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THE BEAM GIVEN BY DIOPTRIC APPARATUS

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ABSTRACT. It is shown that the light in the axial direction given by a dioptric lens using a white source can only be white if the light source is above a certain limiting size. For such light sources a simple expression is deduced for the axial beam candle-power for revolving lenses. A graphical method is given for computing the axial beam candle-power for light sources of smaller size than the critical value. This makes allowance for the variation of luminosity with wave-length for the source used. The distribution of light for directions not on the optical axis is also computed in a general way. The effect of the dispersion of the glass of the lens on the maximum distance at which satisfactory candle-power readings can be made is also considered. The case of fixed lenses is then studied and the general solution obtained for the intensity at any distance and in any direction for light of any colour. From this the candle-power on the horizontal plane is derived as a special case. The rest of the paper consists of numerical results for lenses of the Fresnel section in both revolving and fixed types. Tables to enable the calculation of candle-power to be made are included.

I. INTRODUCTION

ATTEMPTS* have been made from time to time to devise formulae on theoretical grounds which would enable the axial beam candle-power of a dioptric lens to be calculated. These formulae have always taken the form

Axial beam candle-power = Factor × area of lens × brightness of source ...(1),

and have differed in the method of derivation and the resultant values of the correcting factor. None of these attempts has taken account of the effect of the luminosity curve of the light source nor of the chromatic dispersion of the lens. The object of the present paper is to deduce appropriate values of the factor in (1) for various types of lens with particular reference to lighthouse practice.

* Bourdelles, "Luminous power of lighthouse apparatus," *Int. Marit. Congress*, 1893; Brebner, *Proc. Inst. Civil Eng.* **111** 1892–3 (296), **122** 1894–5 (300), **199** 1914–15 (388); Ribière, *Phares et Signaux Maritimes*; Green, *Illuminating Eng.* **20** April 1927 (101).

A lighthouse lens is formed by the revolution about a vertical or horizontal axis of prism sections so designed that the ray from a point source at the focus emerges in a horizontal direction for light of wave-length $\lambda = 5893$. One or both of the faces of this prism element are curved, the curvature being that of the circle corresponding to the theoretical curve which is usually parabolic or hyperbolic. Thus, for monochromatic light of the correct wave-length, a small pencil diverging from the source emerges as a parallel beam after passing through the lens. When the axis of revolution is vertical, the lens sends light to the horizon in all directions and is known as a fixed lens. When the axis is horizontal, the lens sends all its light in one direction, and in order to be seen by observers around the horizon it must be made to rotate—hence the name revolving lens.

Fig. 1 represents a section of a small element of the lens and A is the point of intersection of the tangents at B and C. Light passes from F along $FCBD$ and

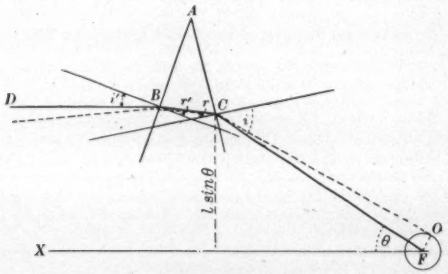


Fig. 1. Refraction through a prism

emerges parallel to FX. The angles i, r; i', r'; and θ are shown in the diagram. It is obvious that

$$\sin i = n \sin r,$$

$$\sin i' = n \sin r',$$

$$r + r' = \text{angle at } A = \text{constant}.$$

Now
$$\delta i' = \left(\frac{\partial i'}{\partial i}\right) \delta i + \left(\frac{\partial i'}{\partial n}\right) \delta n \qquad \text{.....(2a)},$$

or
$$\delta i' = -\frac{\cos i \cos r'}{\cos i' \cos r} . \delta i + \frac{\sin (r + r')}{\cos i' \cos r} \delta n \qquad \text{.....(2b)}.$$

For simplicity, $\left(\frac{\partial i'}{\partial i}\right)$ is written ζ and $\left(\frac{\partial i'}{\partial n}\right)$ is written η in what follows.

Consider now a small spherical source at F. The cone incident at any point of the first prism surface is circular in section and of solid angle $\pi (\delta i)^2$, where

δi is the angle OCF. If the source emits monochromatic light of wave-length $\lambda = 5893$, the axis of the cone is parallel to FX after emergence. The semi-angle of the section of the cone emerging from the prism element, considered in the plane containing the optical axis and the element, is $\zeta\delta i$, and, in the plane at right angles to this passing through the element, the semi-angle is δi. Thus the incident circular cone becomes, after emergence, an elliptical cone with its semi-axes as mentioned above. For light for which the index of the prism is $n + \delta n$, the axes of the ellipse subtend sensibly the same angles at the apex of the elliptical cone but the axis of the cone is inclined to the optical axis at an angle given by $\eta\delta n$.

It follows that a spherical source emitting white light will give rise to a series of overlapping elliptical cones which would appear as a series of overlapping elliptical images on a screen erected at right angles to the optical axis. The semi-axes of the ellipses will be $L\zeta\delta i$ and $L\delta i$ and the centres will lie at a distance $L\eta\delta n$ from the horizontal axis through the element, where L is the distance from the element to the screen. It is obvious from equation (2*a*) that the distance from the nearest edge of the ellipse, for light corresponding to index $n + \delta n$, to the intersection of the optical axis and the screen is $L\delta i'$ when L is very large, and thus the condition that light of a given colour shall contribute to the *axial* beam is that $\delta i' = 0$, that is

$$\zeta\delta i = \eta\delta n.$$

If in Fig. 1 the distance from the element to the source be l, then $\delta i = \rho/l$, where ρ = radius of the source. Substitution in the above expression leads to

$$\rho = l.\delta n \frac{\sin(r + r')}{\cos i \cos r'} \qquad \ldots\ldots(3).$$

This expression gives the minimum size of spherical light source for a given element of a dioptric lens which will allow light, for which the index is $n + \delta n$, to contribute to the beam in the axial direction. For a source emitting white light the axial light will be coloured for sources smaller than that given by (3) when $n + \delta n$ refers to light from the extremes of the visible spectrum, while for larger sources the light will be white in the axial direction. Further, the intensity along the axis will be the same as if all the white light from the source were concentrated uniformly in an ellipse of semi-axes $L\zeta\delta i$ and $L\delta i$ respectively. It is then easy to calculate the axial intensity for sources above the critical size given by (3), but for sources below this size it is necessary to consider the distribution of luminosity in the spectrum given by the source.

The luminosity curve for any given type of light source is given by the product of the energy curve* and the normal eye sensitivity curve†. It is found that such curves for an incandescent gas mantle and a half-watt lamp correspond so closely to one another that their mean has been used for the present purpose. The ordinate at any wave-length is proportional to the illumination in the ellipse, corresponding to the light of that wave-length given by the element of the lens. The curve in

* Luckeish, *Colour and its applications*, p. 21.

† *Proc. C.I.E.* 6 1924 (67).

Fig. 2 represents the luminosity data plotted against values of δn for lighthouse crown glass and therefore gives the distribution along the line of intersection of the plane representing the screen and a plane containing the optical axis of the lens and the lens element when a slit of infinitesimal width placed at right angles to the second plane is used as source. An extended source may be considered as a series of such slits and the resulting distribution is given by the overlapping of the spectrum from each infinitesimal slit with those from its neighbours. This is equivalent to drawing a large number of such curves as that shown in Fig. 2, each displaced horizontally a distance equal to one slit width, and summing the ordinates. In the limit, this is the same as integrating the curve. A maximum is reached when

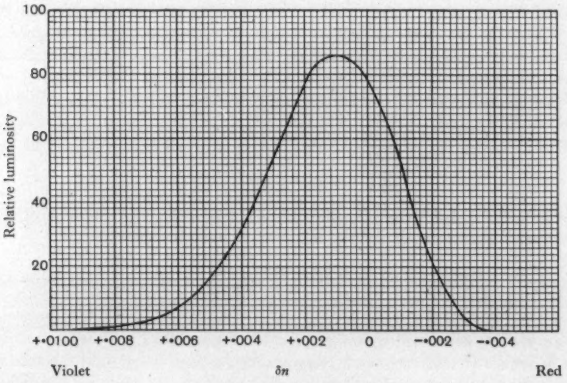


Fig. 2. Luminosity curve

the length of the source (in angular units) exceeds the total divergence caused by the dispersion of the glass reckoned from one end of the visible spectrum to the other. Detailed curves for particular lens forms are given later under the discussion of the different types of lens. The importance of the result, for the present purpose, lies in the fact that the axial intensity reaches a maximum at a certain size of source and increase of the dimensions of the source beyond this only increases the size of the uniform white patch but not its intensity. It is of interest to note that since the curve shown in Fig. 2 is not symmetrical about the axis, a somewhat higher axial intensity could be obtained for small light sources, such as electric filament lamps, by using the value of n for the brightest light of the spectrum (about $\lambda = 5750$) for the design of the lens.

II. Revolving Lenses

(*a*) *The Axial Candle-power for Sources above the Critical Size*

It has been shown that, provided the source be larger than the limiting value given by (3), the intensity in the small cone from any element is the same, in the axial direction, for white as for monochromatic light of the same luminosity and is independent of the size of the source. Also, since the prism rings have curved faces, so that light of a selected wave-length from the centre of the source will emerge parallel to the axis, irrespective of the point through which it passes in the prism ring, the results obtained for an element may be taken as substantially true for a whole prism ring.

Consider two diametrically opposed elements of the lens surface equally distant from the optical axis (Fig. 3). The source will give rise to two elliptical cones which will cross each other at some point dependent on the distance apart of the elements from which they emerge, and on their vertex angles. The appearance on a screen at some distance L will also vary with the distance of the screen from the lens

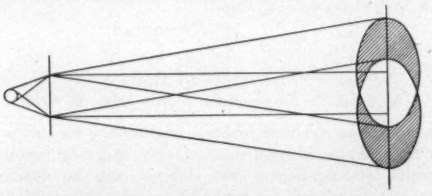


Fig. 3. Distribution of illumination on a screen at a distance

as indicated in the diagram; but at a sufficiently large distance the shaded portions will become negligibly small compared with the central portion. Ultimately this central portion will become elliptical and will be $\pi L^2 \delta i^2 \zeta$ in area, provided the source is emitting monochromatic light. It follows that the beams from a series of elements equidistant from the optical centre of the lens will form a series of ellipses superimposed at infinity and that the axes of these ellipses will rotate about their common centre on the optical axis of the lens (since the diameter of the lens is small compared with L) as the element is moved round the lens. The final distribution from a complete ring element will therefore be a circular patch symmetrical about the optical axis. It will have a central circle of uniform illumination of diameter $2L\delta i$ surrounded by an annulus of decreasing illumination and outside diameter $2L\delta i\zeta$, since in general ζ is greater than unity.

Any small element of the lens surface subtends a solid angle of $\sin\theta.\delta\phi.\delta\theta$ at the focus, if this point be taken as the pole of a system of polar coordinates. If a spherical source of radius ρ and brightness B be placed at the focus, the light flux falling on this element is $B.\pi\rho^2.\sin\theta.\delta\phi.\delta\theta$. This amount of light, less that lost by reflection and absorption, is sent out in the emergent beam from the lens

element. If K represents the overall transmission of the lens at this point, the emergent flux is $KB.\pi\rho^2.\sin\theta.\delta\phi.\delta\theta$. Since the axial intensity from a spherical source emitting white light has been shown (under the restrictions of size of source which have been imposed) to be equal to that from a monochromatic source of the same brightness, this flux gives the same axial intensity as if all of it were uniformly spread in an elliptic cone of solid angle $\pi\delta i^2\zeta$. Thus the axial intensity δI from the element under consideration is given by

$$\delta I = \frac{KB.\pi\rho^2.\sin\theta.\delta\phi.\delta\theta}{\pi\,\delta i^2\zeta},$$

or, since $\rho = l\delta i$,

$$\delta I = KB\frac{l^2\sin\theta.\delta\phi.\delta\theta}{\zeta} \qquad \text{.....(4).}$$

Thus the total intensity on the axis for a source above the limiting value is given by

$$I = B\int_{\phi_2}^{\phi_1}\int_0^{\theta_1}\frac{Kl^2\sin\theta.d\phi.d\theta}{\zeta} \qquad \text{.....(5),}$$

where K, ζ, and l are, of course, functions of θ. For the case where the lens forms a complete circle $\phi_1 = 2\pi$, $\phi_2 = 0$. Thus

$$I = 2\pi B\int_0^{\theta_1}\frac{Kl^2\sin\theta.d\theta}{\zeta} \qquad \text{.....(6).}$$

(*b*) *The Axial Candle-power for Sources below the Critical Size*

In the absence of an algebraic function representing the curve of Fig. 2, it is only possible to obtain the integrated curve (5) by graphical means. From such a curve the relative intensity in any given direction may be obtained for any lens element and the summation of the values of equation (6), multiplied by the ratio obtained from the graphical integration, is relatively simple. Practical instances are quoted in Section IV of this paper.

(*c*) *The Distribution of Light about the Axis*

The method adopted for the calculation of the distribution of light is that used by Blondel and Lavanchy* and Walsh†, with suitable modifications to allow for the effect of variations in n. This method is to discuss the appearance of the face of the lens when viewed from a direction not on the axis, and to plot the areas which appear illuminated from such a direction.

In Fig. 4 CB represents the direction of the axis of an elementary cone of light whose index is $n + \delta n$. The centre of the elliptical cone from C will lie at B, the distance AB being $L\eta\delta\eta$. In the lower part of the figure, O is the projection of the lens centre and A is the projection of C. H represents the position of the observer and, in order that the point C on the lens should appear light, the elliptical cone from that point should form an ellipse on the screen covering the point H.

* Blondel and Lavanchy, *Ann. de Phys. et Chem.* **7** 1917 (249); **8** 1917 (51).
† Walsh, *Proc. Opt. Conv.* 1926 (385 et seq.).

The general equation of an ellipse with B as centre (coordinates p' and ϕ) is

$$\frac{r^2 \sin^2(\phi - \alpha)}{L^2 \delta i^2} + \frac{(r \cos(\phi - \alpha) - p')^2}{L^2 \delta i^2 \zeta^2} = 1,$$

since the semi-axes of the ellipse are $L\delta i$ and $L\delta i\zeta$ respectively, and r is the radius vector with α the vectorial angle. The condition that the point $(h, 0)$ should lie on this ellipse is then

$$\frac{h^2 \sin^2\phi}{L^2 \delta i^2} + \frac{(h \cos\phi - p')^2}{L^2 \delta i^2 \zeta^2} = 1,$$

where h = distance OH.

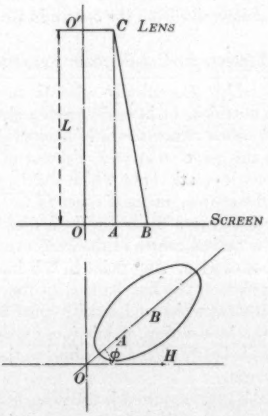


Fig. 4. Distribution of light about axis of lens

If OH subtends an angle β at the lens, then $h = \beta L$ and $\delta i = \rho/l$, whence, for the coordinates of the point A, i.e. the point C on the lens (coordinates p and ϕ),

$$p = l \sin\theta,$$

$$\phi = \cos^{-1} \frac{p' \pm \sqrt{(p')^2 - (1 - \zeta^2)\left[\zeta^2 L^2 (\beta^2 - \rho^2/l^2) + (p')^2\right]}}{\beta L (1 - \zeta^2)} \quad \text{.....(7),}$$

where $$p' = l \sin\theta - L\eta\delta n.$$

When $L \to \infty$ these equations reduce to

$$p = l \sin\theta,$$

$$\phi = \cos^{-1} \frac{\eta\delta n \pm \zeta \sqrt{(\beta^2 - \rho^2/l^2)(\zeta^2 - 1) + \eta^2 \delta n^2}}{\beta(\zeta^2 - 1)} \quad \text{.....(8).}$$

Finally, for the case when $L \to \infty$ and $\delta n = 0$,

$$p = l \sin \theta,$$

$$\phi = \cos^{-1} \pm \sqrt{\frac{\zeta^2 (\beta^2 - \rho^2/l^2)}{\beta^2 (\zeta^2 - 1)}} \qquad \text{.....(9).}$$

From these equations it is possible to plot out the limits of the areas of the lens which appear illuminated to an observer at any point for monochromatic light of any colour. The application to the distribution of light in the beam is indirect since it is necessary to carry out the calculation for predetermined portions of the spectrum to which a mean value of δn and of the luminosity figure may be apportioned. The values of ϕ so found are then used as limits in equation (5) and the final summation gives the intensity from the source in the required direction.

(*d*) *The Minimum Distance for Candle-power Readings* (*Axial Direction*)

The least distance at which theoretically accurate candle-power readings may be taken is that distance at which the intensity from a given lens element is equal to the intensity from the same element in a horizontal direction, i.e. at infinity. It was shown earlier in this paper that each element of the lens gave rise to a number of cones of monochromatic light which overlapped to an extent which depends on the size of the source, amongst other factors. The central portion is white and this white region covers the angle (in a direction parallel to the line joining the element to the optical centre of the lens) over which the extreme red and violet of the spectrum overlap. Any point in this inner cone will receive the same illumination as a point on the line parallel to the axis, so that the nearest point on the optical axis itself at which an intensity equal to the intensity at infinity is received is given by the intersection of this inner cone with the optical axis. This limiting condition is obviously given by the intersection of the cone of extreme *red* light with the optical axis.

Using equation (2*a*), the angle required is the value of $\delta i'$, when δn is the value for the extreme red, and since the edge of the cone required is that on the side of the axis, and the value δn is negative for red,

$$\delta i' = \zeta \delta i - \eta \delta n_R,$$

where δn_R is the value of δn for extreme red.

Also $L \delta i' = l \sin \theta$, where L is the required distance, since $\delta i'$ is small, whence

$$L = \frac{l^2 \sin \theta \cos i' \cos r}{\rho \cos i \cos r' - l \delta n_R \sin (r + r')} \qquad \text{.....(10),}$$

using the result of (2*b*) and the relation $\delta i = \rho / l$. It follows from (10) that $L \to \infty$ when the denominator approaches zero, which leads to

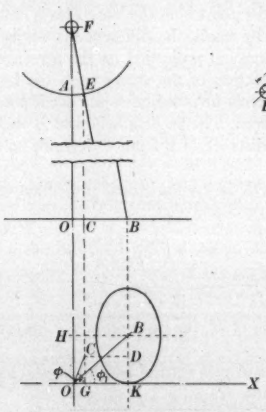
$$\rho = \frac{l \sin (r + r') \delta n_R}{\cos i \cos r'} \qquad \text{.....(11),}$$

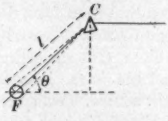
which is identical in form with equation (3). Thus, for small sources, the correct value of the intensity can only be measured at an infinite distance from the lens though the error introduced by measuring the intensity at smaller distances may be negligibly small.

III. Fixed Lens

(*a*) *The Distribution of Light from a Fixed Lens*

In the case of a fixed lens, the light is only restricted in a vertical direction, spreading horizontally in all directions. There is therefore no optical axis to the beam which is symmetrical about a horizontal plane. In the case of revolving lenses it was shown that each element of the lens sent out a beam in the same direction so that from an infinite distance all these elementary beams could be considered as originating from a single point. For a fixed lens (Fig. 5), however, only the elements in a vertical section of the lens send out beams whose axes are in the same direction. Thus any point at a distance from the lens and on the horizontal





Section through lens

Fig. 5. Beam from element of fixed lens

plane through the light source receives light from those portions of the lens whose elementary beams have a greater spread, considered horizontally, than the angle between the extreme element contributing light and the vertical plane through the light source and the observer's position. For light of the index for which the lens is designed, this angular spread is obviously the semi-minor axis of the elliptical section of the cone from any element, but for light of other wave-lengths the ellipse is displaced vertically, and the effective angle is correspondingly reduced. The length of the intercept made by the horizontal plane through a lens element, on the ellipse given by that element, depends on the size of the light source, so that for fixed lights the intensity in an axial direction is still a function of the size of the light source, even when this size is above the critical size as found for a revolving lens. The critical size found previously only referred to the distribution along the

major axis of the ellipse formed on a screen by the light from any element, and since all the small ellipses from the whole lens appear superimposed at a great distance, the resultant light patch was symmetrical about the optical axis. In the present case, the distribution on the screen at a great distance is only symmetrical about a horizontal line and the illumination at any point on this line is given by the summation of the intensities, in the direction of the line joining the light source and the point, of the elementary beams from points on the lens. These contributions can be summed for any given monochromatic light and the result for white light must be found by a graphical integration allowing for the different luminosities for various wave-lengths.

In Fig. 5 F represents the light source in a fixed lens AE. OB is a screen at a distance L from the lens. In the lower portion of the figure the ellipse represents the light patch on the screen from the point E on the lens. This is not truly elliptical but, as the angle CEB is necessarily small, the difference is negligible. B is the centre of the ellipse, C is the orthogonal projection on the screen of the point E on the lens, and OX is the intersection of the screen with the horizontal plane through the light source. Two systems of coordinates are used, p and ϕ referring to the lens and p' and ϕ' to the screen. The vertical height of B above or below C depends on δn and the horizontal distance of B from C depends on the separation of the points A and E on the lens.

From the figure, $OB = p'$ and OK is the horizontal projection of OB, whence

$$OK = p' \cos \phi'.$$

Also
$$OK = \frac{FO.AE}{FA} = p \cos \phi \left(\frac{L + l \cos \theta}{l \cos \theta} \right).$$

It is further seen that

$$BK = p' \sin \phi' = l \sin \theta - L\eta \delta n.$$

If β represents the angular distance of H, the position of the observer, above the horizontal, then $OH = \beta L$.

Any ellipse with its centre at B and axes vertical and horizontal has an equation

$$\frac{(r \cos \alpha - p' \cos \phi')^2}{a^2} + \frac{(r \sin \alpha - p' \sin \phi')^2}{b^2} = 1,$$

where

r = the radius vector,

α = the vectorial angle,

a and b = the semi-axes.

The condition that the point H $(\beta L, \pi/2)$ is on this ellipse is obviously

$$\frac{(p')^2 \cos^2 \phi'}{a^2} + \frac{(\beta L - p' \sin \phi')^2}{b^2} = 1.$$

Since $a = L\delta i$ and $b = L\delta i \zeta$, it follows that, on substitution and reduction,

$$p \cos \phi = \pm l \cos \theta \sqrt{\delta i^2 - \frac{(\beta L - l \sin \theta + L\eta \delta n)^2}{(L\zeta)^2}} \qquad \text{.....(12).}$$

In this reduction, $l \cos \theta$ has been neglected as small compared with L, so that $L + l \cos \theta$ has been written as L.

When $L \to \infty$, this equation reduces to

$$p \cos \phi = \pm l \cos \theta \sqrt{\delta i^2 - \frac{(\beta + \eta \delta n)^2}{\zeta^2}} \qquad \ldots\ldots(13),$$

where $p \cos \phi$ is obviously the semi-width of the lens at θ above the horizontal, which appears illuminated to the observer at angle β above the horizontal plane for light of index $n + \delta n$.

The width of the lens appearing bright to an observer at infinity on the axial plane is given by putting $\beta = 0$ in (13). Thus for this case

$$p \cos \phi = \pm l \cos \theta \sqrt{\delta i^2 - \frac{\eta^2 \delta n^2}{\zeta^2}} \qquad \ldots\ldots(14),$$

which further reduces to $p \cos \phi = \rho \cos \theta$ for light of index n.

(*b*) *The Beam Candle-power for Fixed Lights*

The beam candle-power refers usually to the equivalent candle-power of the lens at any point on the horizontal plane through the light source. In order that light of index $n + \delta n$ should contribute to the power in this direction, it is clearly necessary that the source should be large enough to enable the emergent elementary cone to cross the horizontal plane. The limiting condition is that $\delta i' = 0$ as shown in Section I, for then the emergent beam will travel horizontally. The actual width of the illuminated portion of the lens corresponding to a position at angle θ above the horizontal plane has been worked out in the preceding section and the result is immediately applicable to the case of the horizontal intensity.

The focus of the lens is taken as being the centre of a system of polar coordinates in which θ is the angle between the axis of the cylinder formed by the lens face and the element under consideration, ψ the angle between the element and the line joining the centre and an observer at a distance, and l the radius vector. Then the solid angle subtended by the element is

$$\sin\left(\frac{\pi}{2} - \theta\right) \delta\psi . \delta\theta = \cos \theta . \delta\psi . \delta\theta.$$

The solid angle corresponding to the small beam emerging from this element is $\pi \delta i^2 \zeta$ and, the total flux being $KB . \pi\rho^2 \cos \theta . \delta\psi . \delta\theta$, the intensity after passing the lens is

$$\frac{KB . \pi\rho^2 \cos \theta . \delta\psi . \delta\theta}{\pi \delta i^2 \zeta}.$$

Substituting $l \delta i = \rho$, this expression reduces to

$$\frac{KB . l^2 \cos \theta . \delta\psi . \delta\theta}{\zeta},$$

or in the limit

$$dI = \frac{KB . l^2 \cos \theta . d\psi . d\theta}{\zeta} \qquad \ldots\ldots(15).$$

From the previous section, the semi-width of the lens which appears bright to an observer on the axial plane at infinity is

$$l\cos\theta\sqrt{\delta i^2-\frac{\delta n^2\eta^2}{\zeta^2}},$$

which gives limits for ψ of

$$\pm\sqrt{\frac{\delta i^2\zeta^2-\delta n^2\eta^2}{\zeta}},$$

since $$p\cos\phi = l\cos\theta,$$

or, substituting in (15),

$$dI = 2B\frac{Kl^2\cos\theta\,.\,d\theta}{\zeta^2}\sqrt{\delta i^2\zeta^2-\delta n^2\eta^2} \qquad \text{.....(16).}$$

This equation gives the contribution to the whole beam given by a strip, $d\theta$ in angular width, round a fixed lens for a spherical light source of any size and emitting monochromatic light of any colour. Since the width of the illuminated strip varies with the colour even when the distance from which the lens is viewed approaches infinity, it follows that the light from a white source can never be truly white at any point in the beam. The actual difference is of course frequently negligible in practice. The total beam power is the integral between $\pm\theta_1$ of (16) or

$$I = 2B\int_{-\theta_1}^{\theta_1}\frac{Kl^2\cos\theta}{\zeta^2}\sqrt{\delta i^2\zeta^2-\delta n^2\eta^2}\,.\,d\theta \qquad \text{.....(17).}$$

By similar reasoning, it may be shown that the equivalent candle-power in any direction β above the horizontal plane, for any light of index $n+\delta n$, is given by

$$I = 2B\int_{-\theta_1}^{\theta_1}\frac{Kl^2\cos\theta}{\zeta^2}\sqrt{\delta i^2\zeta^2-(\beta+\eta\delta n)^2}\,.\,d\theta \qquad \text{.....(17}a\text{).}$$

It is only possible to determine the candle-power from a source emitting white light by estimating the candle-power for monochromatic light of various colours and then summing the results after weighting them in accordance with the sensitivity of the eye. This has been carried out in Section IV for the case of Fresnel lenses.

IV. Fresnel Lenses (Revolving Type)

The Fresnel type of refracting prism is characterised by a vertical, plane, inner face. It follows that, in the nomenclature of Section I, $i=\theta$ and the deviation also $=\theta$, or

$$i' = r + r' = \text{angle of prism element.}$$

Hence $$\tan i' = \frac{n\sin r}{n\cos r - 1}.$$

Equation (2*b*) then becomes

$$\delta i' = \frac{-\cos\theta\,(n^2-\sqrt{n^2-\sin^2\theta})\,\delta i + n\sin\theta\,.\,\delta n}{n^2-\sin^2\theta-\sqrt{n^2-\sin^2\theta}} \qquad \text{.....(18).}$$

The values of ζ and η from (18) are given in Table I for various values of θ.

TABLE I

θ	ζ	η	Ratio η/ζ
0°	1·00	·00	·00
5	1·00	·17	·17
10	1·02	·35	·34
15	1·05	·52	·50
20	1·09	·73	·67
25	1·15	·96	·84
30	1·22	1·22	1·00
35	1·30	1·54	1·18
40	1·38	1·92	1·39
45	1·49	2·26	1·52

From equation (3) the value of ρ/l, which will just contribute to the axial beam light of index $n + \delta n$, is given by

$$\rho/l = \delta n\, \eta/\zeta,$$

and, since $l \cos\theta = f$, where f is the focal distance, the least size of source is given by

$$\rho = \frac{f\,\delta n}{\cos\theta} \cdot \frac{\eta}{\zeta}.$$

For the case of white light, the extreme value of δn is about ·010 or

$$\frac{\rho}{f} = \frac{\cdot 010}{\cos\theta} \times \text{ratio from Table I.}$$

The values of ρ/f for various values of θ are given in Table II.

TABLE II. *Minimum size of light source to give white axial light*

θ	ρ/f (radian)	θ	ρ/f (radian)
0°	·0000	25°	·0093
5	·0017	30	·0115
10	·0035	35	·0144
15	·0051	40	·0181
20	·0071	45	·0215

The axial intensity for light sources above the critical size is given by (6). For Fresnel lenses

$$I^2 = \frac{f^2}{\cos^2\theta},$$

or

$$dI = 2\pi B f^2 K \frac{d(\sec\theta)}{\zeta} \qquad \text{.....(19).}$$

K is the transmission factor of the glass at the position corresponding to θ. This is given in Table III for reflection angles as found from the characteristic equations of the lens type and an assumed absorption in the glass of 8 per cent.

The figures in Table III give the beam candle-power as a function of Bf^2 for Fresnel lenses for all spherical light sources which are larger than the largest size in Table II for the outer zone of the lens. For smaller sources, graphical methods must be adopted.

TABLE III. *Light source above critical size*

Values of K and dI for Fresnel lenses (for $d\theta = 5° = \cdot0873$ radian).

θ		K	Figure to be multiplied by Bf^2
0°		·84	·000
5		·84	·014
10		·84	·080
15		·84	·123
20		·84	·166
25		·83	·205
30		·82	·244
35		·80	·288
40		·78	·344
45		·74	·385
Totals	0–30		·737 Bf^2
	0–35		1·003
	0–40		1·329
	0–45		1·693

For any zone corresponding to θ above the axis, the abscissae of Fig. 2 must be increased in the ratio $\eta : 1$, and the resultant curve, similar in character to that of Fig. 2, must be integrated to the appropriate values of $\delta i \zeta$.

The results, for the case of a Fresnel lens, at $\theta = 40°$ are given in Fig. 6 for various values of ρ/f. Then the relative *axial* intensity is given by the height of the ordinate at abscissa = 0, relative to the height of the ordinate for a large source. Table IV gives values of equation (19) multiplied by the appropriate ratio found from diagrams such as Fig. 6.

TABLE IV. *Contributions from different zones to the total axial beam power for light sources below the critical size*

Angular size of source ρ/f / θ	Fresnel lens 6′	12′	30′	45′
0°	·000	·000	·000	·000 Bf^2
5	·040	·041	·041	·041
10	·072	·079	·080	·080
15	·102	·119	·123	·123
20	·121	·156	·166	·166
25	·133	·184	·202	·205
30	·137	·205	·240	·244
35	·130	·219	·279	·286
40	·106	·234	·320	·340
45	·077	·227	·339	·376
	Total intensity from complete lens			
Totals 0–30	·536	·681	·732	·737 Bf^2
0–35	·669	·892	·991	1·002
0–40	·787	1·118	1·290	1·315
0–45	·878	1·348	1·519	1·673

The area of the lens face from which this beam is projected is clearly $\pi (f \tan \theta_1)^2$, so that the values between 0 and various values of θ_1 from Tables III and IV divided by this area give the required values of the factor in equation (1). Table V gives the results.

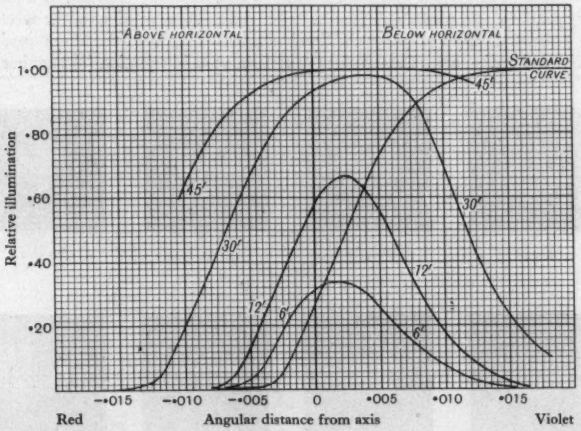


Fig. 6. Relative illumination along the line through the major axis of ellipse. Fresnel section $\frac{\theta}{40^\circ}$

TABLE V. *Values of the factor (equation (1)) for Fresnel revolving lenses*

Angular size of source ρ/f / Value of θ_1	6′	12′	30′	45′	All larger sizes
30°	·517	·657	·705	·710	·710
35	·437	·584	·649	·657	·658
40	·366	·521	·600	·613	·619
45	·280	·429	·484	·533	·538

The factors, then, enable the axial beam power for a revolving Fresnel lens to be calculated from a knowledge of the size of the source and the lens and the brightness of the source, assumed spherical.

The Distribution of Light over the Lens

As a check on the accuracy of equations (7), (8), and (9), a lens was erected with a 12 V. opal bulb as the source of light. The size of the source, which was practically uniform, was such that $\rho/f = 4^\circ{\cdot}6$ and the lens aperture was approximately 40°. A series of photographs was taken by means of a telescope attached to a camera, using panchromatic plates and filters to isolate red and blue portions of the spectrum. The estimated values of δn for the dominant wave-lengths of the filters were blue $+ \cdot 006$ and red $- \cdot 002$. These values were then used in equation (8) together with

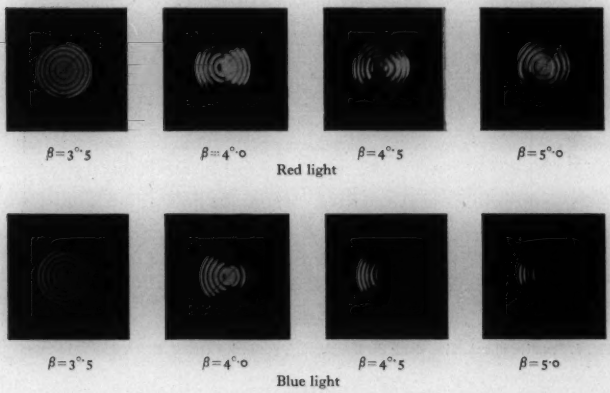


Fig. 7. Photographs of revolving lens for different angles from axis. View from right of axis

values of β of $3^\circ{\cdot}5$, $4^\circ{\cdot}0$, $4^\circ{\cdot}5$, $5^\circ{\cdot}0$, and the resultant equation solved for p and ϕ.

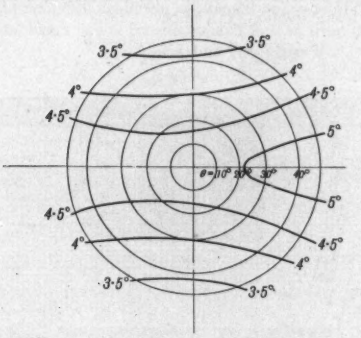
Fig. 7 shows the photographic results and Fig. 8 the calculated curves for the boundaries of the illuminated areas. The agreement is close enough to check satisfactorily the theoretical work.

Minimum Distance for Candle-power Readings

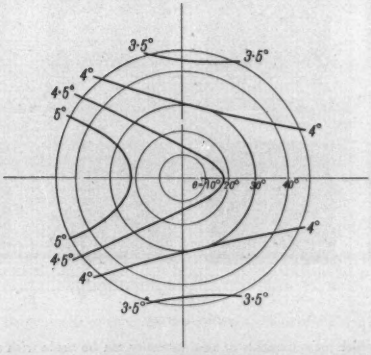
Equation (10) when adapted for Fresnel sections becomes

$$\frac{L}{f} = \frac{\tan\theta}{\frac{\rho\cos\theta}{f}\cdot\zeta - \eta\delta n_R} \qquad \text{.....(20).}$$

The curves of Fig. 9 give values of L/f for change of size of light source. The dotted line shows the corresponding values of L/f when the effect of dispersion is



(*a*) Red light, $\delta n = -\cdot 002$



(*b*) Blue light, $\delta n = +\cdot 006$

Fig. 8. Calculated curves showing the illuminated areas on Fresnel lens. Observer on left of axis looking along the beam

ignored. It is obvious that for small light sources the distance must be increased very considerably over that shown by the simplified theory in order to retain theoretical accuracy.

Fresnel Lenses of the Fixed Type

The distribution of light of any colour over the face of a fixed Fresnel lens follows immediately from equation (13), since

$$l^2 \cos^2\theta = f^2 \text{ and } \delta i^2 = \frac{\rho^2 \cos^2\theta}{f^2}.$$

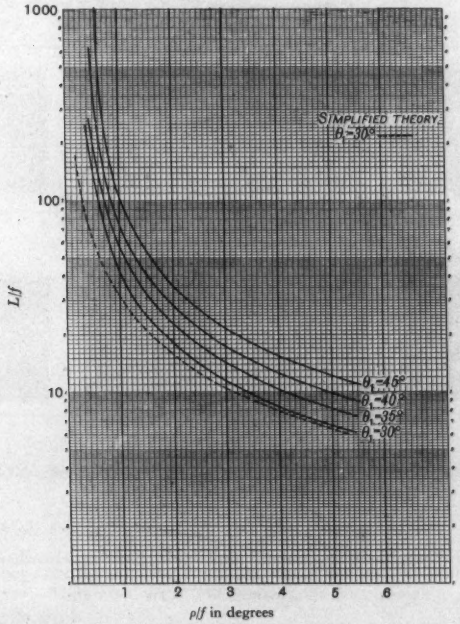


Fig. 9. Distances at which measurements of axial intensity can be made with theoretical accuracy. Fresnel revolving lens

Substitution of these in (13) gives

$$p \cos\phi = \sqrt{\rho^2 \cos^2\theta - \frac{f^2(\beta + \eta\delta n)^2}{\zeta^2}} \qquad \text{.....(21).}$$

Fig. 10 gives photographs, using the same red and blue filters as for the revolving lens, for a fixed lens of focal length 250 mm. with a spherical light source of angular

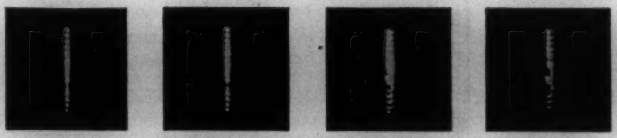
semi-diameter of 4°·6. The photographs show the appearance of the lens for values of β corresponding to 0°, 3°·0, 3°·5, 4°·0, 4°·5 above the horizontal.

Fig. 11 gives the calculated curves from equation (21), the agreement being sufficiently good to confirm again the substantial accuracy of the deductions made.

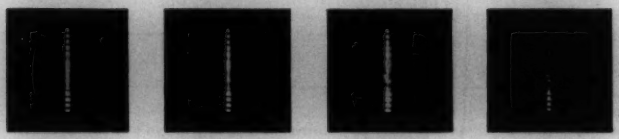
The horizontal beam power for this type of lens is, from (17), given by

$$I = Bf^2 . \int_{-\theta_1}^{\theta_1} \frac{2K . d\theta}{\cos\theta\,\zeta} \sqrt{\frac{\rho^2 \cos^2\theta\,\zeta^2}{f^2} - \delta n^2 \eta^2} \qquad \text{.....(22).}$$

$\beta = 0°$
View from axis



$\beta = 3°{\cdot}0$ $\beta = 3°{\cdot}5$ $\beta = 4°{\cdot}0$ $\beta = 4°{\cdot}5$
Red light



$\beta = 3°{\cdot}0$ $\beta = 3°{\cdot}5$ $\beta = 4°{\cdot}0$ $\beta = 4°{\cdot}5$
Blue light

Fig. 10. Photographs of fixed lens for different values of β above horizontal

This value only applies of course to monochromatic light of index $n + \delta n$. Calculations have been made for values $\delta n = 0, \pm \cdot 002, + \cdot 004, + \cdot 006, + \cdot 008$, and from Fig. 2 average luminosity values have been apportioned as follows:

$\delta\eta = -\cdot 002$	·01
·000	·25
$+\cdot 002$	·38
$+\cdot 004$	·25
$+\cdot 006$	·09
$+\cdot 008$	·02

Averaging the mean results from equation (22), after weighting the values in accordance with these factors, enables the approximate value of the right-hand side of this equation to be obtained for white light of the type used in deriving Fig. 2. Thus the integrated values between $+\theta_1$ and 0 for the case $\rho/f = 1°$ are:

$\delta n =$	0	·002	·004	·006	·008
$\theta_1 = 30°$	·01464	·01464	·01442	·01418	·01380
35	·01672	·01672	·01642	·01608	·01556
40	·01862	·01862	·01824	·01778	·01710
45	·02032	·02030	·01986	·01928	·01820

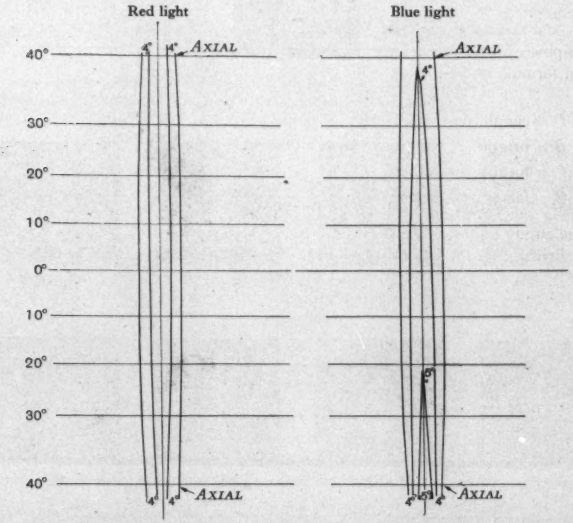


Fig. 11. Appearance of fixed lens from various positions above the horizontal. $\rho/f = 4°{\cdot}6$

Values for white light derived from the above table, after allowing for variations in luminosity, are:

$\theta_1 = 30°$	·01456
35	·01654
40	·01844
45	·02006

Table VI gives the results for white light, as being the only source of practical importance, for varying values of ρ/f.

TABLE VI. *Factors to enable the beam power of fixed Fresnel lights to be calculated*

$I = C\,Bf^2$, where C is given below

$\rho/f =$	30′	1°	2°	3°	4°	5°
$\theta_1 = 30°$	·0142	·0291	·0583	·0878	·1170	·1462
35	·0161	·0331	·0666	·1005	·1338	·1672
40	·0178	·0369	·0742	·1118	·1490	·1863
45	·0191	·0401	·0810	·1220	·1625	·2030

To summarise, Tables III, IV, and VI provide data for the computation of candle-power in a horizontal direction for both revolving and fixed lenses. The general formula is

$$I = CBf^2,$$

where I = candle-power of equivalent point source,

B = brightness of source (assumed spherical),

f = focal length of Fresnel type of lens,

C = factor provided by tables.

The author's thanks are due to Dr H. Moore and Mr R. J. Bracey, F.Inst.P., of the British Scientific Instrument Research Association, for their helpful advice and criticism and to the directors of Messrs Chance Brothers and Co., Ltd., for permission to publish these results.

DISCUSSION

Dr H. Moore: The subject of Dr Hampton's paper, although one of considerable practical importance, is not one likely to arouse great theoretical interest except among a small number of those who are particularly associated with lighthouse and similar work. Consequently a paper of this type is of unusual value since such papers occur comparatively rarely. Probably many members of the Society would, if they had dealt with the subject, have treated the matter in a manner very different from that which Dr Hampton has adopted, and it is possible that a more general method of treatment would give results of a more general character. This must not, however, be allowed to diminish our appreciation of the paper which Dr Hampton has read. Dr Hampton is, in fact, to be complimented on the ingenious method which he has adopted for dealing with the essentials of the problem, a method which is easy to follow and gives all the information it was desired to obtain.

Mr J. R. Wharton: I wish to associate myself with the complimentary remarks made by the previous speaker. There are two points to which I think it worth while calling attention. First, the result of K—the factor which Dr Hampton set out to find—has come out rather higher after further investigation than was shown by his first paper, i.e. the power of the brightest part of the beam is rather higher than was previously suggested. Secondly, Dr Hampton has ended by giving us a value of K as a function of the focus of the lens rather than of the area of the surface illuminated. This gives an easier method of calculation in the case of fixed lenses, where the illuminated area is not so clearly defined or easy to calculate as in the case of those of the revolving type.

Messrs D. and C. Stevenson (communicated): The very interesting investigation which Dr Hampton has made confirms what Lighthouse Engineers have adopted for the powers of lenses. Dr Hampton might have gone a step further and shown how, with relatively large illuminants, the beam power becomes increased when the equiangular form of refractor is adopted instead of the old Fresnel form. The equiangular form is used in all the Great Lights on the Scottish Coast with enhanced brilliancy.

Dr Hampton: I appreciate deeply Dr Moore's remarks on my paper and should like to emphasise here what I have said above, namely, how indebted I am to Dr Moore and Mr Bracey for their valuable assistance in its preparation. Mr Bracey in particular worked through and checked all the formulae and their developments, and even developed the theory on an entirely different line, with the result, very satisfactory to me, that he obtained the same final formulae.

With regard to the points mentioned by Mr Wharton, it may be of interest to indicate the explanation of the slightly increased values of the factors obtained in the present more detailed examination of the question. In the simplified theory put forward in my previous paper I assumed that the spectrum was of equal brightness throughout. I have now made allowance for the variation of luminosity throughout the spectrum, with the result that, if intensity be plotted against angle of divergence, a rectangular diagram is no longer obtained, but one in which the sharp edges of the rectangle become rounded and the intensity along the axis is slightly increased, since the total areas of the two diagrams which represent the total light flux in the beam must be equal. I suggested the new type of formula involving the square of the focal length rather than the luminosity area of the lens, since this one type of formula applies both to fixed and revolving lenses, there being thus no need to make assumptions as to the area which is illuminated in the case of the former type.

The suggestion made by Messrs D. and C. Stevenson has already received some attention and, if it were considered desirable, a table could be prepared showing the relative factors for equiangular, spherical, and hyperbolic lenses. Since, however, the majority of lighthouse lenses which are used at present are of the Fresnel type, I thought it better to put forward detailed calculations for this rather than increase the size of the present paper unduly.

A HISTORY OF THE DEVELOPMENT OF THE TELESCOPE FROM ABOUT 1675 TO 1830 BASED ON DOCUMENTS IN THE COURT COLLECTION

(THIRD PAPER ON THE COURT COLLECTION)*

By THOMAS H. COURT and MORITZ VON ROHR

MS. received, 23rd July, 1929. *Read and discussed, 10th Oct.*, 1929.

SYNOPSIS. I. The optics of the telescope as known when its manufacture was commenced in England.

Lipperhey's influence on the Continent and in England; A. M. v. Schyrle's great invention of the terrestrial telescope with image-erecting lenses in 1645 (made in Augsburg).

II. The old refracting telescopes in England.

Sir Charles Cavendish's acquaintance with A. M. v. Schyrle and some points of similarity between Cock's terrestrial telescope of 1673 and A. M. v. Schyrle's description of 1645. Popularity of telescopes of Schyrle's planning in England in the seventeenth and eighteenth centuries. English improvements and night telescopes.

III. The reflecting telescopes after Gregory and Newton, and their manufacture in London.

The original work of Gregory and of Newton; J. Hadley's impulse; influence on English opticians; Passement's form in 1738; Short's splendid instruments. Caleb Smith's improvement in 1740 and the first publication of his principle of colour correction.

IV. Chester Moor Hall's invention of the achromatic telescope (1729–33) and its marketing by John Dollond (1758).

Relation of the already known facts in historical sequence; invention certainly known to the trade in 1754. J. Dollond's re-invention and publication. Prices of such instruments before and after J. Dollond's death in 1761 and Lord Camden's decision in 1766. P. Dollond's policy as to the prices for achromatic telescopes.

IV A. A digression concerning the gradual appreciation of Chester Moor Hall's merits.

The publications of A. M. de Rochon and Montucla and the work of the more modern investigators A. C. Ranyard, R. B. Prosser, and E. Wyndham Hulme.

V. Sir William Herschel's reflectors.

Knowledge enlarged by Prince Troubetzkoj and W. H. Steavenson. Herschel's influence on English and foreign opticians beyond the period treated here.

VI. The earlier endeavours to avoid a secondary spectrum.

A. C. Clairaut in 1762, R. J. Boscovich about 1767 and R. Blair after 1787, employing different fluids.

VII. Later improvements and modifications of the achromatic telescope.

P. Dollond; H. Pyefinch; brass draw-tubes about 1783; stands folding into a very small compass; W. Worris; C. Varley; the problem of optical glass. The first knowledge of Fraunhofer's instruments; French astronomical objectives of large diameter; the order to Fraunhofer in Munich from Edinburgh Observatory.

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* [The Second Paper on the Court Collection will be published in Vol. xxxi of the *Transactions*.–Ed.]

We do not for a moment profess to be able to write a complete history of English improvements of the telescope from 1675 to 1820 or 1830. Historical studies of this subject are as yet not nearly brought to the necessary perfection, but it now seems possible to lay down some of the principal directions of these improvements. It is hoped that later historians of the telescope will be able to fill the gaps that have been reluctantly left and so in time write a really trustworthy history of the development of the telescope as far as it is to be attributed to master craftsmen, principally of English origin. None of the knowledge that we consider might be of use is withheld and we clearly distinguish between strict evidence and mere hypotheses or suppositions.

I. The optics of the telescope as known when its manufacture was commenced in England

There can be little doubt that the impulse given to optics in 1608 by J. Lipperhey's invention of the telescope speedily brought about universal appreciation of the new instrument. We do not wish to deny that even before 1608 other inventors ((5), pp. 304–7) may have had some useful notions about the telescope, but their ideas did not bear fruit and although put forward again much later they did not influence the actual development of this instrument. Even Lipperhey, who not only constructed the first telescope used for military purposes but also, as early as 1608, solved the problem of combining two such systems to form a binocular instrument, does not appear to us to have definitely laid down the principal lines of the development. It was Galileo's master-mind which showed a new use for the instrument by turning it on the stars. This has always been regarded as of such importance that the designation of "Galilean" telescope has had a long life, although Lipperhey's right to the priority of the invention cannot be disputed. Its designation of "Dutch" telescope is to be preferred since this kind of instrument is now hardly ever used for astronomical purposes. It is nevertheless very remarkable that even during the belligerent period of the Thirty Years' War, begun in 1618, the interest in the scientific aspect of the telescope exceeded its military importance. As every natural philosopher at that time took a very great interest in the new discoveries, many scientific men tried to follow Galileo's example and to prepare with their own hands the instruments that could not then be bought.

As to the construction of Galileo's own instruments we refer the reader to (6). Space does not permit, otherwise it would not be without interest to follow H. Sirturus in his eager endeavours to inspect the original curves of Galileo's telescope. To illustrate the difficulty of preparing good glasses we may cite Gassendi who, in 1634, asked Galileo for a telescope since he had been unable to procure a good one either in Venice, Paris or Amsterdam. Very likely the majority of the exertions as regards the manufacture of useful instruments proved abortive, but even so the work was not quite lost, since the unsuccessful scientific men were able to form a better judgment of the instruments made by their more successful competitors.

In passing we may point to N. Stelliola's work, *Il Telescopio ovvero Ispicillo*

celeste, published in 1627, and to Martin Hortensius, who gave in 1633 a chapter "Proprietates Tubi Dioptrici" in his *Dissertatio de Mercurio sub Sole viso et Venere invisa*.

For an early English specimen of the Galilean form we may refer to S. B. Gaythorpe's two papers (14, 15). It appears that in 1640 W. Gascoigne constructed a Galilean telescope for astronomical purposes which magnified approximately 11 times and had a length of about 40 in. He described the lenses as "London best sale glasses." We can understand that lenses approaching what are in our modern nomenclature + 1 D and − 10 D (by exact measurement these lenses were + 0·87 D and − 9·8 D respectively) could easily be bought from a member of the Spectacle-makers' Company at that date. Later on, Gascoigne turned to J. Kepler's arrangement for the eyepieces of astronomical telescopes, and we may here point to his great inventions, telescopic sights and filar micrometers.

In the earlier times—we specially point to H. Sirturus in 1618—Galileo's ideas were worked out remarkably well in Venice and we learn from him the old way of making sliding tubes of cardboard. This remained *the* standard method for making portable telescopes for 165 years and was occasionally used even 40 to 50 years longer. Needless to say that in this form the larger outer tube invariably bore the object-glass, as the extent of the field depended on its diameter. Hence Italian manufacturers may have been accustomed to this arrangement and retained it for telescopes with eyepieces of collective lenses also, although the above reason did not hold good in such cases. We may point to a specimen of this type by citing (5), pp. 313–14, Fig. 4, where an early Italian model is shown. One of us has carefully examined this telescope and has no doubt that it dates from about 1680 to 1700. At that time Venetian telescopes were apparently sold without competition in the Mediterranean countries. It is possible that Dutch artisans played a similar rôle for the nations living on the coast of the North Sea, but nothing has been saved concerning their work. When in 1637 the above Martin Hortensius assured Galileo that he could not find Dutch telescopes good enough to show Jupiter's disc clearly defined, we must treat this complaint of an astronomer as being similar to that of Gassendi already mentioned. Although an astronomer may not have been satisfied with the performance of these instruments, there is no doubt that Venetian glasses were largely sold to mariners. It may have been the same in Holland.

Even with our restricted knowledge of these old times we must not forget that a very powerful community successfully took up optical problems, viz. the religious orders of Roman persuasion, especially the learned Jesuit fathers. One of their principal authorities at that time was Father Chr. Scheiner. If anybody wishes to convince himself of the earnestness and the success with which such questions were treated he cannot do better than refer to the engraving in the Rosa Ursina of 1626–32. Later on, B. Conrad (10), belonging to the same order, took upon himself to collect and to publish all the practical rules available concerning the making of astronomical telescopes. This was a plan that could only be conceived and executed by a scientific community that had no pecuniary interest in the possession of such rules. There is no doubt that the work of the religious orders was taken up later by

the master artisans in order to supply the wants of scientific investigators. However, the great services initially rendered by the ecclesiastical workers must not be forgotten, and we shall show how the time came when the master artisan in his turn was removed from his important position in telescope optics on account of his inability to fill it.

Fig. 1. Optical instruments of the Jesuit fathers of about 1630. There are three different telescopes for astronomical purposes, all of them after Galileo's plan

Notwithstanding the part played by the Jesuit fathers in the development of optics, they were not without competition from other religious orders. With regard to the terrestrial telescope we must expressly mention a member of the Capuchins. His name was Antonius Maria v. Schyrle, better known at that time as Schyrlaeus de Rheita, or, shorter still, Rheita. We do not know the names he received in baptism,

as he took Antonius Maria when becoming a friar. He was the son of an old family of Bavarian origin and seems to have been born on their estate at Rheita. In time he filled an important post in his order; in 1645 he describes himself as "Ordinis Capucinorum concionator et Provinciae Austriae ac Bohemiae quondam praelector." To obtain his proper name correctly was not without difficulty, but

Fig. 2. A. M. v. Schyrle's manufacturing optician in Augsburg, Johannes Wiesel, in his 77th year

fortunately we found one of the copper-plates in his large book dedicated to his brother Albert v. Schyrle, who was then Imperial Lieutenant-Colonel in Überlingen. In 1645 he printed the following cryptic rules for an erecting eyepiece made of three collective lenses: "Convexa quatuor melius dicta objecta erigunt multumque amplificant; rite vero tertium in punctum colloca confusionis: sunt vero vitra ocularia tria convexa, objectivum quartum*."

* The secret consisted in first pairing the words (the paired ones are carefully chosen of nearly equal length) and then writing the letters in their right sequence but alternately. Hence *convexa quatuor* will give *cqounavteuxoar*. All the odd letters then give the first word, all the even the second.

Although he is careful not to tell too much, we find on pp. 352 and 353 of his book that he preferred to have the exit pupil of his telescope at the back focus of the eyelens, that the eyelens was to be put into the largest of the draw-tubes, that diaphragms had to be arranged inside the tubes and that in his newest instrument he had provided four of them. On p. 356 he observes (without, however, giving exact details) that the use of so many draw-tubes may allow the initiated to obtain different magnifications with the same instrument. Rheita does not seem to have prepared his instruments with his own hands, but gave the work to two opticians* at Augsburg, Johannes Wiesel and Gervasius Mattmüller. A portrait of the first of these has been saved and in it he is seen holding a telescope with a large number of draw-tubes. Unfortunately the artist apparently had no great knowledge of these instruments, so that very little is learned regarding the construction of this old telescope.

A paper by Williams (54) describes an old telescope made by Campani, who had a great name as an optician, which was sold into England about the year 1674. The specimen described had a length of about 10 ft. (3·03 m.), a clear aperture of $1\frac{1}{2}$ in. (3·8 cm.) and a magnification of about 20 ($2p' = 1{\cdot}9$ mm.). When shut, its length was about 2 ft. (61 cm.) and the weight was only 2 lb. 11 oz. (1·22 kg.).

II. The old refracting telescopes in England

We do not know exactly when refracting telescopes were first made in England, although we suppose this to have been early, since the need of these instruments at that time for naval purposes must have made them as much in demand in London as in Venice.

For some time these instruments were probably formed by using a positive lens of greater and a negative of smaller focal length. If ((5), p. 311) in 1641 this combination was still in use for astronomical purposes, where it would be particularly unsuitable on account of the small field with high magnifications, we may safely suppose that it was then widely used on ships.

Even in 1661 telescopes of the Galilean plan were made in England. One of us knows that Mr Mayall was in possession of such a piece with a focal length of 40 in. It had two draw-tubes of wood and the two ends were protected by circular leather-covered caps. The name of Jacob Cuningham (this was J. Cunningham, F.R.S.) was stamped on the cap for the objective end. The plano-concave eyelens was a disc of glass ground on the edges, with a clear concavity in the centre. The whole instrument was of trumpet shape and covered with crimson leather with gold stampings. When it was sold by auction on the 11th June, 1909, lenses were unfortunately missing and only the tube was left.

We may be certain that terrestrial telescopes were objects of great interest in England and we find this corroborated (17) by a number of Sir Charles Cavendish's letters between 1641 and 1645. The first glass made to his order by Reeves was evidently of Galilean type, but in January 1644 he (being then in Hamburg)

* Note the early use of the expression *Opticus*.

obtained some information concerning v. Schyrle's erecting telescopes that were manufactured at Augsburg. As shown in Section I, this knowledge was quite correct. He was very keen on this subject and even went to Antwerp in March 1644, where he made v. Schyrle's personal acquaintance at a time when the latter was busy preparing his voluminous book which was published the following year ((42)). Almost at the same time, on 5th November, 1646, B. Monconys also applied to the inventor of the terrestrial telescope for one of these instruments. We cite the following paragraph (vol. I, p. 117): "Il obligea le Père Rheita à luy en travailler une à quatre verres & luy fit à cette occasion et à toute la maison des présents qui valoient quatre fois la lunette. Et dix ans après il a fait travailler au mesme Divini un télescope de quinze palmes [1·15 m.] à 5 Verres et au beau-fils de Viselius"—is that perhaps the above-mentioned Wiesel? (this was Campani the optician)—"un Microscope qu'il estimoit beaucoup."

Returning to Cavendish's order, we do not expressly hear of his receiving the telescope from Augsburg, but it may be supposed that he bought one and that the Schyrlean construction thus became known in England.

This supposition is strengthened by the examination ((7), Fig. 3) of a very old English telescope made in 1673 or 1675 by the then well-known optician Chr. Cock. We observe the following points which correspond with v. Schyrle's description: The outer tube carries the eyelens; the eyepiece consists of three convex lenses; the exit pupil coincides with the back focus of the eyelens; four stops at different places of the inner tube are provided. With regard to the other details it cannot be said whether or not they can also be ascribed in part to the Schyrlean model. The erecting system is formed of two lenses each of $f' = 9$ cm. at a distance apart of 19·3 cm.; in consequence, the focal length of the erecting system is of negative sign and of the considerable length $-$ 62·3 cm. In erecting the image formed by the objective its size is hardly altered, so that the magnification of the telescope is very nearly given by f'_1/f'_4. [In Cock's system as shown ((7), Fig. 3) the distance between the last erecting and the eyelens must be made equal to 16·5 cm., in order to obtain an afocal system.]

As no specimen of the Augsburg telescopes has been saved, we are not able to decide the above question of dependence, but we may observe that some description, taken from v. Schyrle (vol. III, p. 136), is given in J. Zahn's volume of 1685–6. The drawings of such a telescope showing four convex lenses (vol. II, p. 188, Icon VIII, and vol. III, p. 138) are in close accord with the representations in various English shop prints of that time. We may take it that these descriptions and drawings are genuine because Zahn gives them without any explanation and without referring to any foreign source, as was his wont in similar cases. If this supposition is granted, we may refer to the table (vol. III, p. 137) giving the focal lengths of the different lenses. Taking the Roman foot in accordance with v. Schyrle as 31·1 cm., we obtain for an objective of 3 ft. the following focal lengths:

Objective 93·3 cm. Erecting lenses 7·0 cm. Eyelens 6·22 cm.

Magnification (approximately) 93·3/6·22 = 15.

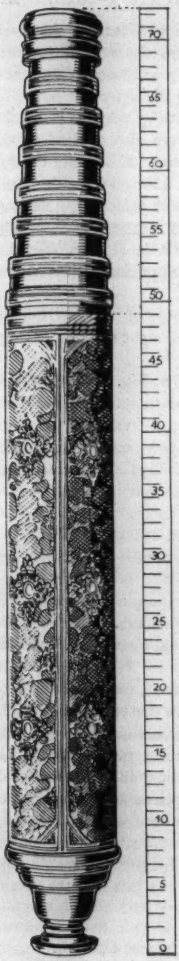


Fig. 3. Chr. Cock's Schyrlean telescope in Mr Whipple's collection, partly drawn out, with a scale in centimetres

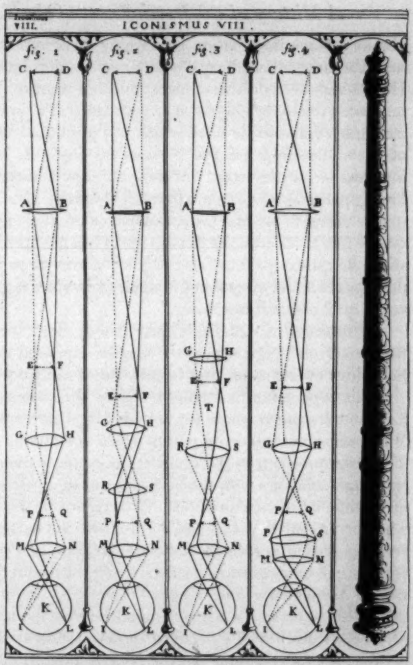
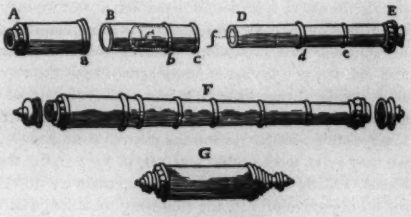


Fig. 4. J. Zahn's plate for Schyrlean telescopes of 1686. The arrows are drawn without reference to their correct positions



Collocato imprimis ſpecillo objectivo in Tubi arundine minori circa *E* committantur aliæ arundines *cd D*, ut in figurâ apparet; diſponatur etiam ad *D* media

Fig. 5. J. Zahn's woodcut for a Schyrlean tube with two lines of the description (½ natural size)

For Cock's telescope of 1673 the corresponding numbers (7) are:

Objective 91 cm. Erecting lenses 9 cm. Eyelens 6·3 cm.

Magnification (7) = 14 (approximately), which is 91/6·3 approximately.

Cock probably deviated from the (supposed) old prescription by making the erecting lenses somewhat weaker. We may also ascribe to him the convenient eye-rest for bringing the pupil of the observer immediately into the exit pupil of the telescope. Zahn's corresponding devices were inferior. Other makers perhaps constructed their terrestrial telescopes more in accordance with Zahn's way, making all three lenses of the eyepieces of the same power, as may be inferred from (3) pp. 19, 20; but they also retained for the erecting part the function of erection only, without materially contributing to the magnification of the whole telescope.

We are indebted to Mr Baxandall for the remark that the Schyrlean form had an advantage for the user in the distribution of the weight of the different parts: the part thrown out farthest was the lightest. We cannot give any reason for the fact that old instruments after the Schyrlean plan have been as yet nearly exclusively found in England, and we know of only one specimen preserved in the Deutsches Museum in Munich. However, they must have been largely used in Germany, as Zahn's book with its very wide distribution shows.

As to the form of the lenses in the eyepiece, we may suppose that bi-convex lenses were retained in the majority of cases. It was quite an innovation when in the book ((116)) edited by Desaguliers the eyelens for the Gregorian telescope was a meniscus.

There is no doubt that both forms were in use in Great Britain from about 1670 till 1725 or 1730. The smaller hand telescopes had the eyelens at the smaller end of the tube; the larger forms, which generally could be used both for celestial and terrestrial purposes, had the eyelens at the larger end of the tube, i.e. after the Schyrlean model. (These had often two object-glasses of different focal length; one for celestial and the other for terrestrial use.) In this way we may explain the fact that both forms appear in Yarwell's shop prints; in the reproduction (Fig. 7) we find the older form, whereas in later specimens (wood-cuts) the Schyrlean arrangement occurs more often. We find this last one exclusively in an old shop print by Willdey and Brandreth that might be dated back to 1712. Afterwards this peculiar form gradually disappeared but traces of it remained and it was still advertised by E. Culpeper in 1725 and after. From another source (3), pp. 12, 13) we must suppose that even in 1750 the old Schyrlean form was still alive—in the Court Collection there is an octagonal mahogany body for a chromatically uncorrected telescope of this kind by Ayscough, dated about 1750.

We may say briefly, therefore, that from 1670 to about 1725 the Schyrlean form of the terrestrial telescope had a good market in England but after the introduction of the achromatic object-glasses this form gradually disappeared.

It must not be forgotten that about this time there was a very remarkable amount of telescope manufacture in the North of Italy, where well-known artists were at work. We may cite Petrus Patronus of Milan, who as Imperial Optician was at work in 1726, and Leonardo Semitecolo. The latter must have had a rather large

factory for small inexpensive telescopes, for quite a number of them still exist. They are generally covered with crimson paper stamped in gold designs; the draw-tubes are in green or creamy vellum and the tubes protected by horn mounts. The object-glass is held by the outer tube. On a similar line was the work of Franciscus Sansedonius living at Naples in 1730. One of his specimens had an aperture of $\frac{3}{4}$ in. and 2 ft. 8 in. focal length; when the four draw-tubes were pushed in, the length was $10\frac{3}{4}$ in. Both ends were protected by ivory caps. We may mention also the Selva family in Venice. The father Domenico (about 1758) and the son Leonardo (at work in 1787) were skilled workmen well known to us by the pamphlets of the latter. They

Fig. 6. Marshall's woodcut of a Schyrlean telescope

were evidently, like other Venetian opticians (e.g. B. Burlini), instructed in English methods and must be considered as more efficient than their Venetian competitors.

P. Dollond[13] in 1789 mentions the fact that in Newton's time (say the beginning of the eighteenth century) telescopes, opera glasses, etc., were imported from Italy, and in particular from Venice, in great numbers, as the artisans there were favoured with the command of the useful Murano glass. We cannot set aside this statement as unreliable on the ground that P. Dollond was not an eyewitness, for when he established himself about 1750 the time mentioned was not so far distant that trustworthy eyewitnesses could not have related to him a great deal about the optical situation at the earlier date.

In 1750 G. Adams and R. Jack (3) took out the often-mentioned patent for a terrestrial telescope. In their compound eyepiece the erecting system had also the function of magnifying the image. The new telescope was thus much shorter, being, as the description states, only 4 ft. long instead of 12 or 15 ft. It is a pity that no exact data that can be examined by calculation are given. We also gather from the description that in 1750 greater stress was laid on the form of the lenses. It seems as if the plano-convex lenses were being gradually preferred for the eyepieces, and for the eyelens even a meniscus* was recommended. It seems possible that about this time the 4-lens form of the erecting eyepiece that we find so well worked out in Ramsden's time was gradually developed. The 5-lens eyepiece recommended by J. Dollond in 1753 was not favourably received by the London opticians.

In any case portable refracting telescopes with cardboard draw-tubes, and others with one principal rigid tube for mariners, were advertised up to 1758 and later. We must mention Short's sealed paper (43) dated 1752 with the rules for properly figuring such object-glasses.

About 1750 telescopes with a brass draw-tube and wooden body were made for use at sea. Their body was either mahogany or (for the cheaper kinds) deal coloured to resemble mahogany, and often octagonal to prevent movement with the rolling of the ship. (It was found that the salt water injured the vellum-covered tubes.) Sometimes they had square heads with more than one object-glass (see also p. 242), that is to say, object-glasses of various powers that could be interchanged and used according to the state of the weather. The same kind of telescopes with one draw-tube (generally of a greater length) were made for military use (see the later improvements with brass draw-tubes on p. 242). The night telescopes for mariners must also be mentioned here; they were planned with the object of giving a magnified image with as much light as possible. For this purpose the erect position of the image was sacrificed, and the mariners really bought astronomical telescopes with object-glasses of considerable diameter and astronomical eyepieces. This form appears to have lasted for more than a hundred years without great alteration or improvement, as we may conclude from a criticism by Fraunhofer (not dated, but very likely after 1809). He complained that the field of the English night-glass shown to him as a model was too small in extent.

Another improvement, but on the mechanical side, is the sliding heads† which, according to T. H. Court's researches, were invented by E. Culpeper about 1711. There is an illustration of a much later time in (5), p. 318, Fig. 10 B. The sliding heads for the object-glass were replaced later by metal caps, whereas the sliding heads for eyepieces had a very long life. They were taken up in the mounting with

* The meniscus eyelens is rarely found in telescopes much after 1750; up to this time it nearly always occurs as the eyelens in the eyepieces of reflecting and sometimes (but not very often) of refracting telescopes.—T.H.C.

† They were advertised (in J. Good's book *The Art of Shadows and Universal Dialling*, 1711) by "Ed. Culpeper at the Old Mathematical Shop under the Crossed Daggers in Moorfields as Pocket telescopes with silver or brass slyding (*sic*) heads." The larger kind of telescopes of the opening years of the eighteenth century are still often found provided with screw caps for the objective and the eye end.—T.H.C.

the sliding brass tubes and were still constructed with a rotary instead of a sliding movement.

There is no doubt that J. Marshall's improvement in the year 1693 ((11), p. 8) of surfacing a number of lenses, with not too short a radius, together on blocks did a great deal to improve the workmanship of the London opticians. Telescope objectives especially must have been made after this process with a much higher degree of accuracy in London than elsewhere.

Regarding hand-glasses of Galilean form there is in the Court Collection a very interesting report* of a comparison between English and continental hand-glasses, dated 1696. The foreign glasses had been imported from Holland and were decidedly inferior to the English specimens. We both suppose that the home-made glasses had been figured by Marshall's process, so that a much better finish of the surfaces was to be expected, as Marshall's process was not practised abroad at that time.

III. The reflecting telescopes after Gregory and Newton, and their manufacture in London.

The history of the reflecting telescope from the beginning down to the year 1723, when John Hadley succeeded in producing the first successful large reflector, was collected (16) by J. T. Desaguliers in 1735 with great care and study. The book has given us very exact and useful data.

The first to publish the idea of a catadioptrical telescope was James Gregory† in his *Optica Promota* of 1663. He planned (pp. 93–4) a parabolic concave speculum, near whose focus was to be placed a small elliptic concave speculum. Nine years later (in 1672) he thought of replacing the small concave speculum by a plane one. As he himself was unable to figure an aspherical surface, he asked a London optician Rives [later Rives (Reeves) and Cox (Cocks)] to try. The experiments then made with spherical mirrors did not turn out well, and he gave up the idea of bringing such telescopes into use.

When Newton applied himself to the grinding of object-glasses with aspherical surfaces in 1666 he was deterred by discovering the different refrangibility of light, and turned his attention to reflecting instruments. He intended giving to his concave mirror a parabolic surface as he did not approve of Gregory's plan, neither of that of Cassegrain (published in 1672), but preferred his well-known arrangement with the plane mirror throwing the image formed by the concave to the side of the body of the telescope. A great many trials were made with regard to the figuring, and

* In No. 197, dated 1696, of a *Collection of papers for the improvement of Trade and Husbandry* by John Houghton, F.R.S., it is stated: "As to the 4 doz. Prospect glasses imported from Holland they amount to nothing worth speaking about & they are of a mean sort, for Mr. Yarwell in St. Paul's Churchyard & Mr. Marshall in Ludgate Street & divers others have brought the art to such perfection as that I do not doubt that for good ones they will vie with the best Foreign Workman." This paper also mentions a "John Cock's Prospective Glass Grinder at the Cock & Garter in Long Acorn" (*sic*! instead of Acre).—T. H. C.

† The late H. Erfle pointed to a still earlier case, as in 1644 Mersenne recommended two concave parabolic mirrors in order to form a reflecting telescope.—M. v. R.

to the discovery of a metal free from pores and with a high reflecting power. In the year 1672 he writes of reflectors with an aperture of $1\frac{1}{3}$ in. (34 mm.) that allowed him to read a page of the *Philosophical Transactions* at a distance of between 100 and 120 ft. ($30\frac{1}{2}$ and $36\frac{1}{2}$ m.) using a magnification of about 40.

A discussion with J. Gregory was held with great courtesy on both sides, but it appears that Cassegrain's merits were then not fully recognised. Afterwards opticians agreed in considering there to be three different types of the older reflecting telescopes and gave them the names Gregorian, Newtonian and Cassegrainian.

With the year 1673 experiments came to an unsuccessful end and Desaguliers (16) mentioned that up to 1723 he did not know of any efforts to put the theoretical plans of three or four French scientists into practice.

Progress was resumed when John Hadley took up the old ideas in 1720. He first made Newtonian telescopes and then turned his attention to Gregorians. There were different trials of his instruments in 1721 (?) and 1723 and up to 1726, when he published an account of his perfected Gregorian reflector. The difficulties of figuring the surfaces were decidedly great, but his reflector of $5\frac{1}{4}$ ft. (1·60 m.) focal length compared favourably with the great refracting instrument made by Huygens of 123 ft. ($37\frac{1}{2}$ m.) focal length. There is no doubt that the hopes of astronomers were very great at that time, and that they expected the difficulties arising from the small reflecting power of the mirror from tarnishing and from figuring would soon be cleared away, and there was a suggestion to make a hollow glass lens silvered on the back.

Much later Sir James South pointed to the fact that in 1728 the French scientist Le Maire communicated to the Paris Academy a plan for a reflecting telescope with a tilted mirror. As this arrangement was not adopted by Herschel for his larger instruments before 1786, Sir James South (48) designated this kind of reflecting telescope the "Le Mairean" arrangement. We shall not follow him in this proposed alteration but continue to use the term "Herschelian." It appears to us that the difficulties to be overcome by Herschel were so great, and his success so decisive, that the homage done to him by attaching his name to this instrument ought not to be withdrawn.

Hadley had made his first instruments with his own hands, and under his influence and with his encouragement and instructions J. Bradley soon began to work in the same direction. Later on he continued his exertions, together with S. Molyneux, and in May 1724 they succeeded in finishing a mirror of 26 in. (66 cm.) focal length. At that time the optician Hauksbee (in Crane Court) had also made such an instrument for public sale and his mirror of $3\frac{1}{2}$ ft. (1·07 m.) focal length was commended by Molyneux. When Bradley and Molyneux were satisfied with their progress they instructed two opticians, E. Scarlett (near St Anne's Church, Soho) and Hearne (in Dogwell Court, White Friars), in their processes. Molyneux mentions especially the mirror of his own reflecting telescope with 5 ft. focal length and an aperture of 6 in. (aperture ratio = 1 : 10) as being made by Hearne.

Shortly after this time a careful examination of different telescopes was made,

under Dr Bevis' auspices, on 16th December, 1736, at Islington. We are able to condense the results given in the *Report** as follows:

Maker	Form	Aperture		Magnification	Diameter of exit pupil (mm.)
		(in.)	(mm.)		
Scarlett	Gregorian	2 (nearly)	50	36	1·4
Chaplain	,,	$1\frac{7}{8}$	47·6	40	1·2
Short (Edin.)	,,	2·3	58·4	61	0·96
Scarlett	Cassegrainian	4 (almost)	100	100	1·0

We learn that quite a number of opticians had begun to take up manufacture and that it was nearly a universal rule to choose the magnification in such a way that the exit pupil was about 1 mm. in diameter. Although it is mentioned in the report of this examination that the construction adopted was that of J. Gregory, we hear nothing of the aspherical surfaces. If we suspend judgment with regard to the greater mirror, we may express a doubt whether the smaller was really of an elliptic form.

Three years after Desaguliers had brought out D. Gregory's work in the second edition and had shown to a wide circle of scientists and artists all the advantages that could be derived from reflecting instruments, some effects became noticeable. In Paris Cl. S. Passement brought out—according to Poggendorff—his book in 1738 (27) especially dealing with reflecting instruments as he recommended they should be made. How great the interest was in the optical world may be concluded from a pirated copy of Passement's work (4) brought out in Amsterdam in 1741. It apparently contained Passement's work enlarged by some additions from other (as yet unknown) sources. The compiler's knowledge was very limited, for he confounds, as we shall see, Newton's work regarding the reflecting telescope with that of

* We know of two different examinations. On 25th September, 1736 (Add. MSS. Brit. Mus. 4433)—Dr Bevis and others being present—there took place an examination of two telescopes, one a reflector and the other a refractor made by W. Molyneux, F.R.S., also a reflecting telescope made by James Mann (magn. 36); the performance was not good. "They also tried a Gregorian telescope of $5\frac{1}{2}$ in. by Short. It magnified as I remember 37 times and was the first reflector he ever made."—Again on 16th December, 1736, at Islington Dr Bevis, Mr George Graham, Mr Caleb Smith, Mr Thomas Heath were present, and at a further trial Martin Folkes, President of the Royal Society, and his son, Mr George Graham, Mr Richard Graham, Mr Mitchell and Mr E. Scarlett were present. The following telescopes were examined:

(1) A metallic one according to the construction of Mr James Gregory in his *Optica Promota* by Mr Scarlett of London; the focal length of the object metal, 9 in.; its aperture 2 in. barely; it magnified 36 times.

(2) A metallic one, also of the Gregorian construction, made by Mr Chaplin of London; the proportionate size of the parts nearly the same as the former save that the aperture was $1\frac{7}{8}$ in. and its magnification nearly 40 times.

(3) A metallic one of the Gregorian form made by Mr Short of Edinburgh; the focal length of the object metal 9 in. or a very little more, its aperture 2·3 in. Mr Graham told us the maker had informed him that it magnified 61 times.

(4) A metallic one of the Cassegrainian form made by Mr Scarlett, the smaller metal being convex; it had three eyeglasses; the focal length of the object metal being 2 ft., its aperture almost 4 in.; it magnified about 100 times.—T. H. C.

Gregory. We do not think that in this book all the patient labour, principally of English scientists, that had been spent from 1663 downwards was duly appreciated,

Fig. 7. Gregorian telescope, after Passement's description of 1738

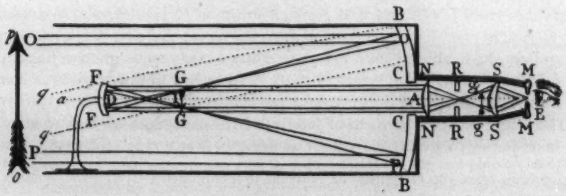


Fig. 8. J. Hadley's Gregorian telescope of 1726, after J. T. Desaguliers

but it was decidedly useful to bring a part of these achievements before the technical experts in general. There were many omissions. We do not hear anything of mirrors with aspherical surfaces, a perfection sedulously aimed at in England (Passement

restricted himself to spherical surfaces); neither do we believe that the method of paper-polishing there described was to be compared with Newton's system of pitch-polishing. As we do not wish unduly to disparage this book, we should like to emphasise the advantage of bringing together the rules and principles of the art known to the author. We are also indebted to him for his carefully drawn copperplate with the exterior of a Gregorian telescope, evidently after the English fashion, by which the outward form of these instruments in 1738 is known (not long after the decisive impulse given by J. Hadley, F.R.S.). If we compare this drawing with the clumsy and graceless Fig. 4 added by Desaguliers to his book, we see the difference between the optical artist desirous to sell his instruments and the optical scientist satisfied with an illustration for his descriptive text. We may mention an idea of preparing a small reflecting telescope of 7 pouces (7½ in.) length with a light simplified stand attached to the tube of the telescope. There is no doubt that the endeavours of the English artists were very soon directed to the same end. We are afraid, however, that many of their inventions are now lost to us. In 1747, six years after the publication of the pirated print, a German translation with a great many annotations and

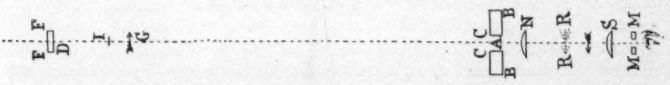


Fig. 9. The optical parts (near the axis) of J. Hadley's Gregorian telescope of 1726; the instrument, of 12 in. focal length, is rendered ¼ natural size

remarks was brought out by J. Chr. Hertel (18). He had some connexion with the then famous philosopher Chr. Wolff (had perhaps attended some of his lectures) and Wolff wrote a preface to his book. Whereas nothing particular can be said as regards this translation, the preface is well worth reading. Wolff points out that Passement attributed to Newton the idea belonging to Gregory and made Hertel correct this mistake in his title (not in the text). He also gives a useful and reliable history of the English endeavours from J. Gregory and Newton down to J. Hadley, and artists' names such as Scarlett and Short are included. As he repeatedly cites the book edited by Desaguliers, he is able to give this interesting history with great reliability. We do not know of any foreign scientific work of so early a time that gives as complete an account of this optical improvement and its development.

The following advertisement of Jean van Musschenbroek of Leyden may fit in this same period; we can only date it as being between 1725 and 1738.

	flor.	S.M.	£	*s.*	*d.*
Un fort beau télescope Grégorian de nouvelle invention qui a 16 pouces (43½ cm. = 17 in.), et qui est posé sur un beau pied: il fait le même effet, qu'un télescope ordinaire garni de verres et qui seroit de 10 pieds (3·25 m. = 10⅔ ft.)	70	126	5	12	0
Un autre de 27 pouces (73 cm. = 28¾ in.)	140	252	11	4	0
Un autre de l'invention de Mr Newton de 4 pieds (1·3 m. = 4¼ ft.) de long.	250	450	20	0	0

About this time (1740) Caleb Smith* published a remarkable paper (46) on the improvement of reflectors. His large mirror consisted of a glass mirror silvered at the back. But although this possibility had been already suggested, he mentions another property that had not been thought of before. Since the light passes twice through the protecting meniscus there are necessarily colour aberrations; under-correction for a collective and over-correction for a dispersive meniscus. In his first case the thin collective meniscus silvered at the back has a focal length of 18·3 in. but its chromatic aberration only corresponds to a weak lens with a focal length of 218 in. and may, therefore, be easily corrected by a dispersive lens made of the same glass. Smith recommended Newton's construction with a plane inclined mirror for the second reflection, as the Gregorian disposition might be of rather difficult execution. In the second case the colour aberration of a negative meniscus may be corrected by an additional collecting lens. He also hoped to correct the spherical aberration in his new arrangement. As to the ghosts due to the reflection at the free surface, he did not expect great disturbances as the image formed there should be sufficiently distant from the principal image.

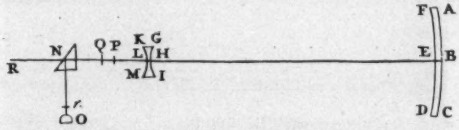


Fig. 10. Caleb Smith's reflector with protected mirror surfaces. The chromatic errors of the protecting lens are destroyed by a negative lens at *LH*

As far as we know no attempt had been made at that time to construct an astronomical telescope of this description. But the idea of correcting the chromatic errors is the first as regards publication. Chester Moor Hall, it is true, had then already finished his remarkable invention, but it was not published. C. Smith's merits in effecting achromatism had been pointed out by B. Martin (22) in 1759.

There is no doubt, and Mr Baxandall ((5), p. 315) has already pointed to it, that from 1723 onwards the London artists took great pains to turn out good reflecting telescopes. Newton's form was not forgotten, as the greater convenience it offered in observing stars at a great distance had often been pointed out, but Gregory's idea, so well adapted to terrestrial use, was much preferred by the general public. Especially J. Short, who soon left Edinburgh for London, made himself deservedly famous for his splendid work. We must concede that as yet no exact measurements have been made of his instruments and that at present we are not able to assert the degree of exactitude he attained in making them parabolic. We can only insist on

* There were some inventions of this very original mind at a somewhat prior date. In a footnote on p. 228 we cite an extremely rare book of his on a Sea Quadrant published probably in 1735. He also invented two ingenious astronomical instruments for use at sea to obtain the longitude by means of observing the eclipse of Jupiter's satellites. In all these cases he used glass prisms instead of simple mirrors. We may already trace here his later idea of a mirror protected by glass.—T. H. C.

the fact that they enjoyed the highest reputation. If we study his old instructions of 1751 for giving a true spherical form to the lenses for his refracting telescopes, we have the impression that he had successfully followed the direction for figuring spherical surfaces that had been first given by Newton. We are able by the courtesy of Mr Frederick Stimpson of Lee Road, Blackheath (the owner), to include what is believed to be an authentic portrait of James Short, F.R.S., the celebrated maker of reflecting telescopes. After fully considering all the evidences in its favour we have little doubt but that this painting represents him.

Short was able to turn out a large number of instruments at very fair prices. The system according to which he numbered* his instruments has been published by D. Baxandall ((5), p. 316):

"The instrument in Fig. 7, for instance, is engraved: $\frac{244}{1063} = 9{\cdot}6$. From an examination of a series of his telescopes, including a few dated examples, it would appear that the numerator is the rotation number of the instrument of that particular size (i.e. focal length or diameter of mirror), the denominator is the number of telescopes made up to date, and the third number gives the focal length in inches."

* I give below the details which I have to hand of various instruments of Short's. There are others but I cannot find them. The first two have the dates 1741 and 1744.

Size	Engraving	
	$\frac{1}{312} = 37$	This was a 6 in. object metal, Gregorian and Newtonian combined, made for the Earl of Macclesfield when he was president of the Royal Society. It was afterwards used by Sir William Huggins, F.R.S., for photography chiefly in solar work.
2 in.	$\frac{37}{405} = 7$	This screwed on the lid of the box to form a stand ((5), Fig. 7).
2 in.	$\frac{154}{1017} = 7$	,, ,, ,, ,,
	$\frac{244}{1063} = 9{\cdot}6$	,, ,, ,, ,,
3 in.	$\frac{25}{384} = 12$	,, ,, ,, ,,
3 in.	$\frac{69}{567} = 12$	Tripod stand.
3 in.	$\frac{150}{934} = 12$	This screwed on the lid of the box to form a stand ((5), Fig. 7).
4 in.	$\frac{189}{1190} = 18$	Tripod stand.
4 in.	$\frac{205}{1205} = 18$	,, ,,
4 in.	$\frac{229}{1203} = 18$	,, ,,
4½ in.	$\frac{236}{1283} = 18$	,, ,,
	$\frac{6}{1346} = 49$	,, ,,
3 in.	$\frac{209}{1178} = 12$	,, ,,
3 in.	$\frac{38}{474} = 12$	,, ,,
2½ in.	$\frac{241}{1172} = 12$	,, ,,
	$\frac{37}{1037} = 24$	,, ,,

It is not generally known that other makers made use of a similar system. I have found the following:

(1) 3 in. Gregorian by J. Birdstrup, London: $a/ah = f/kf$.

(2) 3 in. ,, ,, Thomas Short (James Short's brother): 12 = 257.

(3) 3 in. ,, ,, Nairne, London: $\frac{2}{119} = 48$. This was Edward Nairne, F.R.S., optician (born 1726, died 1806), afterwards Nairne and Blunt.

These are all I have ever seen of other makers similarly marked, so such pieces must be rare. Thomas Short's instrument (2) is the only one I have seen or heard about. Of Nairne's reflectors I have seen a fair number, but none marked like (3).—T. H. C.

Needless to say we must not compare the numbers of Short's instruments sold to his customers with those of our time. Quite apart from the smaller population in the eighteenth century, the masterpieces of art and industry were then reserved for the aristocrats. A telescope made by Short was at that time justly considered an optical gem, and we know that in 1765 one of his reflecting telescopes was sent to R. J. Boscovich from the Duke of York as a gift and in acknowledgment of some service done to him by the Paduan professor.

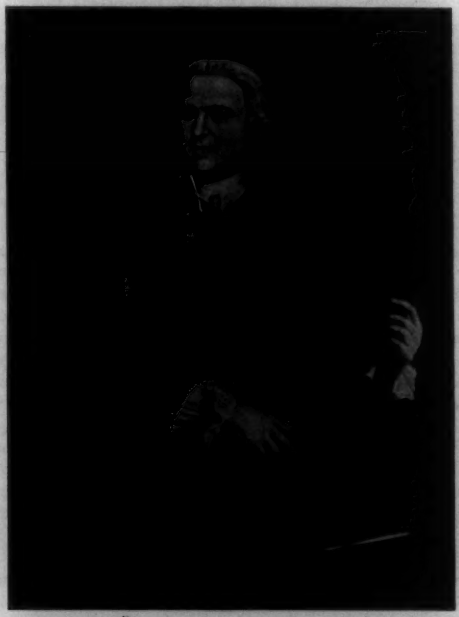


Fig. 11. Portrait of James Short. By kind permission of Mr Frederick Stimpson (the owner), after restoration by Herr O. Trinkler

Short's knowledge and ability were rewarded by the Royal Society in electing him a Fellow of that illustrious body, and at the time of his death he was decidedly in a better financial position than the majority of his professional brethren.

We are able to insert a short price-list of his that has been saved from oblivion by Dr H. Schröder. In reproducing this list we have added a column for the aperture ratios and a column for the exit pupils with the various magnifications.

From the year 1768.

Table of the Apertures, Powers, and Prices of Reflecting Telescopes, constructed in the Gregorian form, by the late ingenious Mr James Short.

No.	Focal length		Diameter of aperture		Aperture ratio	Magnifying powers				Exit pupils, 2ρ (mm.)				Prices (guin.)
	(in.)	(cm.)	(in.)	(cm.)										
						Times								
1	3	7·6	1·1	2·8	1 : 2·7	1 : —	—	—	18	—	—	—	1·5	3
2	4½	11·4	1·3	3·2	: 3·5	1 : —	—	—	25	—	—	—	1·28	4
3	7	17·8	1·9	4·9	: 3·7	1 : —	—	—	40	—	—	—	1·22	6
4	9½	24·2	2·5	6·4	: 3·8	2 : —	—	40	60	—	—	1·60	1·07	8
5	12	30·5	3·0	7·6	: 4·0	2 : —	—	55	85	—	—	1·38	0·9	10
6	12	30·5	3·0	7·6	: 4·0	4 : 35	55	85	110	2·17	1·38	0·9	0·69	14
7	18	45·7	3·8	9·7	: 4·7	4 : 55	95	130	200	1·76	1·02	0·75	0·48	20
8	24	61·0	4·5	11·4	: 5·3	4 : 90	150	230	300	1·27	0·76	0·5	0·38	35
9	36	91·5	6·3	16·0	: 5·7	4 : 100	200	300	400	1·60	0·80	0·53	0·40	75
10	48	122·0	7·6	19·3	: 6·3	4 : 120	260	380	500	1·61	0·74	0·51	0·39	100
11	72	183·0	12·2	31·0	: 5·9	4 : 200	400	600	800	1·55	0·77	0·52	0·39	300
12	144	366·0	18·0	45·7	: 8·0	4 : 300	600	900	1200	1·52	0·76	0·51	0·38	800

From the last column but one we gather that he allowed (evidently for astronomical use and for the larger instruments) such values as 0·38 mm.* It appears from this list that in general he recommended in telescopes with a number of different magnifications only one for terrestrial purposes, all the others being intended for astronomical observation. No. 6 alone is an exception to this rule, as it offers the choice between two low magnifications for terrestrial use. As Short's example was universally followed at that time, we must suppose that customers asked for such high powers generally. It is worthy of interest that Fraunhofer was obliged in 1816 and later to follow this example with the magnifications for his refracting telescopes, although we have our doubts whether he would have gone to this extreme of his own free will.

Even a master of Short's distinction felt difficulties in the figuring, as we must gather from the column for the aperture ratios. They decrease with the numbers (No. 11 excepted), i.e. with the focal lengths of the larger mirror, so that for the greatest focal length the aperture ratio is only 1 : 8.

We know that in this time, when many rich people took an interest in optical goods, showy and luxurious articles were sold, even when their optical value was inconsiderable. Tiny reflecting telescopes were made, and one of these is to be found in the Fugger Collection at Augsburg. A Gregorian reflector (adjustable for the observer's eyesight) of about 6 in. focal length and 1 in. clear aperture has been hidden in the handle of a walking stick. This bronze handle has been beautifully wrought and gilded afterwards. We suppose that this luxurious piece was bought abroad and brought to Augsburg, but we cannot find the maker's name.

* We must not forget that we find in Hadley's directions (Des. 254) very small openings of the stop arranged between the eyelens and the eye; this stop was designed to eliminate stray light. Diameters such as $\frac{1}{32}$ in. (0·725 mm.) are given.

That Short's instruments served as models in different places cannot be doubted. We know of a memoir written in 1781 (published in 1787) where J. Edwards gave directions for figuring the large mirror with a parabolic surface. We do not see that the means recommended by him for this purpose will infallibly lead to this result, but we cannot doubt that for spherical surfaces his rules for polishing were really useful, and we learn how much value was attached to reflecting surfaces at a time when achromatic telescopes had already been on the market for nearly 25 years.

The influence of J. Gregory's ideas and the example of scientists like Hadley and artists like Short, the latter serving as the representative of the London

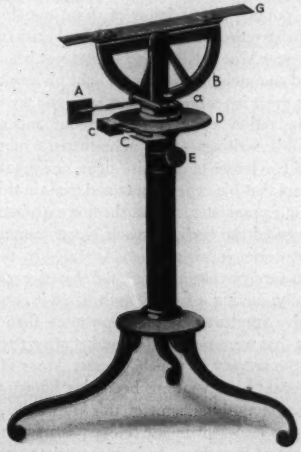


Fig. 12. Stand for Gregorian telescopes, after Robison [died 1805 (see (34))]

artisans of the middle of the eighteenth century, reached so far that Gregorian telescopes on stands continued to be made in England as well as abroad up to the first quarter of the nineteenth century. These Gregorians were not replaced by the achromatic glasses until the art of glassmaking was much farther advanced. Even Fraunhofer as a young journeyman wished to try his hand at this problem, as he proposed in March 1807, in his twentieth year, to bring out a Gregorian telescope with a focal length of 12 pouces (32·5 cm. = 12·8 in.), an aperture of $3\frac{1}{2}$ pouces (9·5 cm. = 3·84 in.), and an aperture ratio of 1 : 3·4. He intended to build an elaborate machine for grinding and polishing his aspherical surfaces, but his employers did not approve of his plan and so he was spared the task of figuring a hyperbolic surface with a faultily planned arrangement.

IV. Chester Moor Hall's invention of the achromatic telescope (1729–33) and its marketing by John Dollond (1758)

Chester Moor Hall (baptized 9th December, 1703, died 17th March, 1771) was a gentleman of property educated for the law (he was a practising barrister and a bencher of the Inner Temple and later became a county magistrate in Essex), but he also took great interest in natural sciences. We take from a book* written by Caleb Smith the following sentence: "About the same time" (before Hadley's Quadrant was described in the *Phil. Trans.*) "or before this, if I am rightly informed, Mr Hall, an ingenious *Gentleman* of the *Temple*, invented an *instrument* of the *like* kind, but as it was never made publick, that I know of, I am not able to give any *particular* description of it." We have therefore C. Smith's authority for the early invention of a Sea Quadrant by Chester Moor Hall; this fact has not been pointed out by any of the historians who did so much in bringing to light his work on achromatic glasses.

With regard to his great invention of the achromatic telescope he was of opinion that the image on the retina was free from colour and conceived the idea—in opposition to Newton's writings—that achromatism might be effected by an objective consisting of two lenses of opposite signs, one made of crown and the other of flint glass. It appears that his experiments and trials in this direction were begun in 1729 and finished four years later, so that the first satisfactory objective was ready in 1733. He did not grind the lenses himself but communicated the radii of the different surfaces to opticians in his employ. As stated by the best authority in this connexion (but unfortunately as late as 1790), the objective was spherically corrected, as well as chromatically, having a focal length of 20 in. and an aperture of more than $2\frac{1}{2}$ in. The relative aperture was therefore more than 1 : 8 and much larger than in the telescopes that were put on the market after 1758.

It is certain that the secrecy of which Chester Moor Hall seems to have been very fond did not prevent his inventions becoming known to some of the London opticians. For a long time nothing came of this knowledge, as apparently the performance of the ordinary non-achromatic telescopes was sufficient for the majority of the London opticians at that time. As in many other cases, the optical improvement was not acknowledged at once: a certain time had to elapse before the public in general appreciated the value of the innovation. From the authority quoted above we are able to state the fact that in 1754 the well-known London optician, James Ayscough, was in possession of one of Hall's telescopes. Another specimen belonging to the Rev. Smith of Charlotte Street, Rathbone Place, was examined at a later date by scientific methods and found to possess the properties of an achromatic glass.

This apathetic attitude was changed by the exertions of John Dollond (born 10th April, 1706, died 30th November, 1761). He changed his occupation from that of a weaver to that of an optician in 1752 and began somewhat later to construct an achromatic object-glass for a telescope, an endeavour that was to bring him

* *The Description and Use of a New Instrument or Sea Quadrant.* London (about 1735). 40 pp., 8vo. One plate. In the Court Collection.

great prosperity and fame. We may safely assert that he was aware of Moor Hall's achievements and we are in fact able to point out the year, 1755, and the intermediary, R. Rew, through whom he received the necessary knowledge. On the other hand, we must grant that J. Dollond had himself a better appreciation of the advantage of colour correction than all the other London opticians of that time put together. Neither do we doubt that he experimented independently to develop the idea that may have been communicated to him in quite a rude form. His invention was completed on the 19th April, 1758.

It was probably not possible at that time to execute elaborate optical experiments in absolute secrecy; at any rate Benj. Martin advertised in 1757 "Dalond's" Glasses, but did not print any prices. There is a curious mistake in the name, as generally it was misspelt "Doll*a*nd." The vowel *a* was often used at that time in Dollond's name, and we remember having seen an etymological derivation of his name given as d'Hollande. In the following year, 1758, the year of Dollond's patent, B. Martin is more explicit with his goods, but omits the name of the inventor. He advertised:

	£	*s.*	*d.*
Telescopes with 6 glasses one foot:	0	18	0
ditto two feet:	1	07	
„ three „	1	16	
„ four „ for sea:	1	16	

In his catalogue of 1762 he advertised patent refracting telescopes of various lengths with 4, 5, or 6 glasses at a guinea per foot. It will be of interest to cite his prices in 1742 (he was not in London then but used different agents for the customers in the metropolis). He charged for old refractors with single objectives:

	£	*s.*	*d.*
Telescope: two feet:	0	7	6
„ four „ :	0	18	0

The prices for new telescopes were more than four times as great.

We do not find the expression *achromatic* in the advertisements of that time. This designation was introduced by Dr Bevis, but the exact date is not known; we can only say that it occurs in one of the catalogues of James Ayscough, and as this optician seems to have died in 1762 or soon after, we must date back the use of this term to 1760–1. An advertisement in 1763 of a certain M. Allison of Falmouth, in which achromatic telescopes are mentioned, fits in with this assumption.

When Dollond's innovation had been patented and the Copley Medal had been awarded to him by the Royal Society, the interest of the public in the new instruments was very great and Dollond's house deservedly profited by it. We cannot doubt that other London opticians soon followed B. Martin's example and openly advertised and sold the new glasses. The proprietor of the patent himself did not object to this practice; he was evidently unwilling to run the risk of a lawsuit since Chester Moor Hall's telescopes were known to so many technical experts.

After John Dollond's death in November 1761 the situation became different. Peter Dollond, the elder son and the head of the firm, warned his competitors against the selling of the new glasses without paying him a royalty. His standpoint may

have been the same at that time as it was when J. Kelly's *Life of John Dollond* (20) was published. We quote from p. 13 of the third edition: "And when the fact could no longer be disputed, they endeavoured to find a prior inventor, to whom it might be ascribed, and several conjecturers were honoured with the title of discoverers." Needless to say, we do not agree with this disparagement of Hall's work.

We cannot determine at what time P. Dollond's action was first resented by his optical brethren in London, probably not before the case was brought into the law courts. We may conclude from a petition against Dollond's patent signed by a number of London opticians and instrument makers that feeling was strong against P. Dollond. This document, presented in 1764, was discovered before 1917 by Mr E. Wyndham Hulme, and there is an interesting note in the Court Collection showing that the S.M.C. contributed money towards this petition. The petitioners alleged that the method was not new at the time of the patent, that John Dollond obtained previous knowledge of Chester Moor Hall's invention, and that object-glasses of that description were made and publicly sold in England before the spring of 1758.

After R. B. Prosser's researches (28) we may suppose that P. Dollond brought the first action for infringement before the beginning of 1766. The defendants were Addison Smith and Francis Watkins (not Wat*son*), both opticians in St Martin's Lane. The action does not seem to have come to trial, but P. Dollond carried his point.

It was different with the second case against Jos. Champneys (alias Champness) (12), an optician of Cornhill. Although this case was never fully reported, we know from brief notices in the daily press (e.g. *Gent. Mag.* **36** 1766 (102)) that the action was tried in February 1766 in the Common Pleas before Lord Camden (not Lord Mansfield) and that Dollond obtained a verdict with damages assessed at £250. The real sum, however, appears to have been £204*. The judge is reported to have said: "It was not the person who locked up his invention in his scrutoire that ought to profit by a patent for such invention but he who brought it forth for the benefit of the public." This decision has often been cited in patent trials.

The last action was brought by P. Dollond against Henry Pyefinch of Cornhill, optician, and it appears to have taken a similar course to that of the first action against Addison Smith and Francis Watkins.

The real inventor—and even Lord Camden did not call in question his priority—did not break his taciturnity: there is no paper known where he opposed Dollond's patent or claims, and he had been dead nearly twenty years before his priority was brought before the public.

We may safely assume that after the verdict against J. Champneys in February 1766 no London optician dared to sell these glasses without paying royalty to P. Dollond as long as the patent lasted (April 1772).

B. Martin (23) in his book *New Elements* declared himself against the achromatic glasses in 1759 but appears to have given in at a later date. He advertised in 1762 "Refracting Telescopes of various lengths and prices with 4, 5 or 6 glasses, the

* It was, however, J. Champneys' ruin, as a few weeks after his name appeared in the *London Gazette* as a bankrupt.—T. H. C.

Patent a Guinea per Foot." The same price is quoted in his list of 1768. The same amounts were charged by George Adams in 1766:

The new Achromatic Refracting Telescope	£	s.	d.
with seven glasses two feet	2	2	0
„ ditto three feet	3	3	0
„ ditto four feet	4	4	0

and so in proportion for any other length.

The same advertisement* also occurs in his list of 1771. But after the patent became void in 1772 the firm of George Adams, directed now by the son, had in the list of 1777 the notice: "Acromatic telescopes from 1 ft. to 8 ft. at 16*s.* per foot." Bringing forward this evidence we may safely assert that the Dollond firm was able by means of the royalty to maintain high prices in the London market.

The early portable achromatic telescopes were generally covered in green shagreen. The sliding tubes were cardboard covered with vellum. Of a great number made between 1760 and 1780 nearly every one answered to this description. Later brass tubes were sometimes used instead of vellum. The outer bodies were made in mahogany and more rarely of Sheffield plate. Such a piece, beautifully engraved, is in the Court Collection. At the end of the eighteenth century till about 1840 mahogany or whalebone was used, and then leather onwards to the present day.

The object-glasses made by John Dollond were binary systems for telescopes and triple lenses for opera glasses and perspectives.

The impression on the scientific world was very great, especially as such an eminent authority as Newton had been shown to be wrong. The credit for this was exclusively attributed to J. Dollond, and in scientific circles of that time Chester Moor Hill's name does not appear.

It is easily understood that attempts to construct achromatic glasses were made abroad. We have some particulars about the optician Cl. S. Passement (27) of Paris, already mentioned, who presented to King Louis XV in 1761 an achromatic opera glass and in 1763 an achromatic telescope. Both had decidedly smaller apertures than the glasses offered by Dollond for similar purposes. The reason for this was the insurmountable difficulty of procuring in Paris optical glasses of larger diameters.

* The knowledge (referred to in J. Bernoulli's *Letters*, p. 71) of an advertisement by Pyefinch of 20th January, 1769, is in good accordance with it.

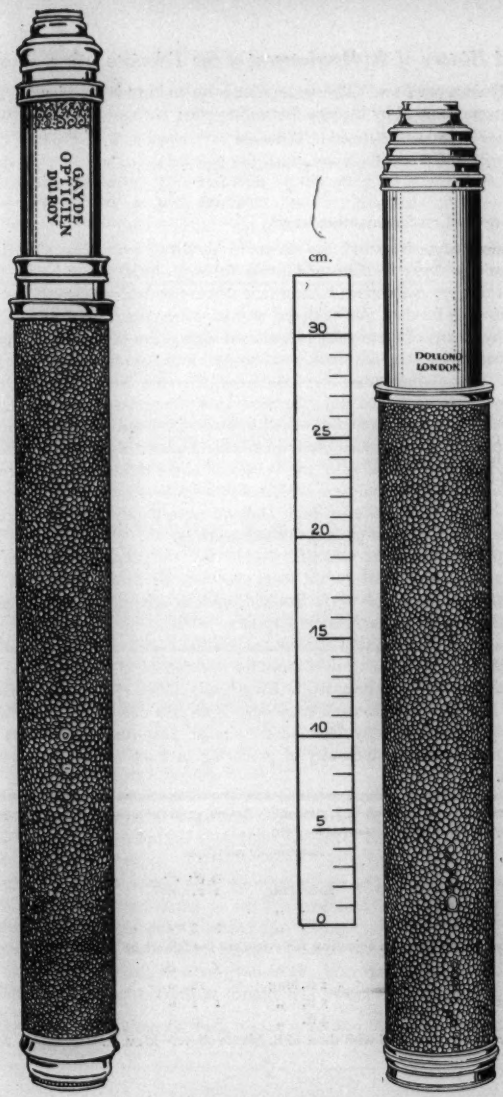
Achromatic telescopes

	£	s.	d.
20 in. long	1	11	6
2 ft. „	2	2	0
3 ft. „	3	3	0

For telescopes with single lens objectives the prices are the following:

	£	s.	d.
2 ft. long		18	0
3 ft. „	1	1	0
4 ft. „	2	2	0

These latter may be compared with those of B. Martin above.—M. v. R.



Figs. 13 and 14. Nurse skin telescopes by Gayde and Dollond, reduced to the same scale

We are informed by C. Scherffer, S.J., a Viennese scientist well versed in optical matters, that at a later period a Dresden optician offered achromatic telescopes for sale at remarkably low prices. Nothing more has as yet come to our notice concerning this Dresden optician and his goods.

About this period we hear rather vaguely but from different sources that the Dollond house had been fortunate enough to acquire in the North of England a great quantity of specially good glass, but unfortunately little more is known than the fact itself. This fact was universally admitted and used in later times to explain why the aperture of the earlier objectives made by Dollond was relatively large; later on the size of the available lenses decidedly diminished. We shall refer again to this question towards the end of our paper.

IV A. A digression concerning the gradual appreciation of Chester Moor Hall's merits

As already mentioned, we must suppose that in 1764, when the petition of the London opticians was formed with the object of having Dollond's patent annulled, Chester Moor Hall's merits were fully known and appreciated by a large number of technical experts (the London opticians). Among the scientific men of that time it may have been somewhat different. The isolated Essex scientist, with his fondness for secrecy, probably had little in common with the natural philosophers in the Royal Society of that period, and he was evidently less appreciated by them than J. Dollond, who had been made a Fellow of that distinguished body in consequence of his world-famous new telescopes. We have already pointed out that Chester Moor Hall did nothing himself to vindicate his rights of priority in the scientific or commercial world. It is no wonder therefore that the Royal Society did not acknowledge them, and that the theory of achromatism was invariably linked with Dollond's name. P. Dollond (13), the son, brought out different editions of his father's life written by his brother-in law, P. Kelly, but Chester Moor Hall was not even mentioned therein, and his endeavours, as mentioned above, were vaguely described as unfounded.

The first champion of Hall did not arise before the autumn of 1790, when an anonymous author, "Veritas" (53), evidently possessing a great deal of exact knowledge, gave a vivid picture of the facts in question. In order to appreciate justly the importance of this article it must be remembered that nearly 60 years had passed since Hall's success, that Hall's telescope had been shown in Ayscough's shop 36 years before, and that it was 24 years since the judgment had been given in Dollond's favour. In looking attentively at this article we observe that although the writer made some mistakes in the names such as Klinginstierna, Chester *More* Hall, Lord Mansfield (instead of Lord Camden), he was well acquainted with optical facts and with the names of opticians. He appears to have been quite familiar with Bass and Ayscough, and, if he belonged to the trade, he was probably an expert of many years' standing. There were not many opticians in London in the year 1790 who fulfilled these requirements and it is not impossible to ascribe the article to Jesse

Ramsden (born 6th October, 1735; died 5th November, 1800), who was 19 years of age when Hall's telescope was shown in London. He himself declared before Dr Tilloch (see *Phil. Mag.* **2** 1798–9 (177)) that the article by "Veritas" contained a true statement of facts and in this connexion allowed his name to be mentioned as a witness. Another account by A. M. de Rochon agrees—after due correction of the faulty spelling—with that of "Veritas," and the mistake of Lord Mansfield's name occurs again in the French narrative. If de Rochon's account of a misunderstanding in 1790 between the two brothers-in-law, P. Dollond and J. Ramsden, is correct then we may make a guess why "Veritas" published his account in the same year.

The article by "Veritas" was highly appreciated in England and it appears that its rendering of Hall's name as Chester More Hall was universally accepted, until A. C. Ranyard (31) corrected it in 1881. In the Court Collection, however, there is a cutting taken from *The British Magazine* of 22nd March, 1766, concerning a capital offence which was tried by Chester Moor Hall as a county magistrate. Personal acquaintances of his certainly knew then the correct spelling of his name.

P. Dollond did not refute the article by "Veritas," and the whole question would perhaps have been abandoned if it had not been revived in consequence of the discussion regarding a French article on the same topic. As already mentioned, A. M. de Rochon, a French physicist, had evidently heard some talk concerning Hall's merits during his sojourn in London in the summer of 1790. He expressly referred to Ramsden as his principal authority, but he had consulted other sources as well. Unfortunately de Rochon was not a writer of any precision, and in 1798 (35) he published an account full of minor mistakes and with a doubtful spelling of proper names, but evidently founded on some evidence obtained in London. We cannot wonder that this narrative was not received favourably eight years later; the war against France did not inspire the reviewer in the *Philosophical Magazine* (36) with a wish to do justice to such a crude article. In 1801 de Rochon tried to justify himself against this criticism. His second paper (37, 38) was a corroboration of the first and the author, with his very indifferent gift of precision, related to the best of his power some rather romantic version about Hall's invention that he may have heard in London in 1790, and the way in which J. Dollond became acquainted with Hall's plan and the verdict of the judge in favour of Dollond.

Another French version which appeared in Montucla's *History of Mathematics* of 1802 (25) is shorter and more to the point. It is ascribed to the then famous astronomer de Lalande and was probably communicated to him by English men of science. The proper names are spelt with much greater correctness and we find here too a statement of the fact that Dollond obtained some knowledge of Hall's invention. The case against Watkins has been put into the first place as in de Rochon's version, as if the verdict had been given in this trial. Even if we do not learn more detail, we obtain a glimpse into the position of this historical question among English scientists during the latter part of the eighteenth century.

In the first years of the nineteenth century the interest in London in this controversy seems to have considerably slackened. The witnesses of the lawsuit gradually died out, whereas the plaintiff, P. Dollond, who had reached a very

advanced age, was universally respected. It is thus easily understood that during his lifetime this question was not raised again. So we find in T. Young's historical portraits (see J. Dollond) only a short note (55) on Hall's alleged discovery, but otherwise the credit is given to Dollond.

As time passed, the greater became the effort needed for the removal of obstacles in dealing with this old question. We learn that in 1868 an Upsala scientist, Wackerbarth, pointed to this problem, but we fully realise the difficulties in reading A. C. Ranyard's first article of 1876 (30). By persevering studies and with the effectual help of R. B. Prosser (28) and E. Wyndham Hulme a great many forgotten points were brought to light again. The proper spelling of the name, the history of Chester Moor Hall's Essex family, the three different law cases out of which P. Dollond came triumphantly, were secured beyond any doubt (32, 33), and Hall's priority as the real inventor of the achromatic telescope was fully established. To Mr E. Wyndham Hulme belongs the merit of having discovered the text of the petition of 1764. So that we are now fully able* to do justice to the real inventor who had been so long forgotten.

V. Sir William Herschel's reflectors

Before continuing the history of the development of the achromatic telescope we will examine briefly the treatment Newton's reflecting telescope received in Herschel's hands. We must remember that although Newton's form of the reflector was never wholly forgotten—on the contrary the greater facilities provided by it in observing stars at a great altitude had been repeatedly pointed out—the majority of the instrument makers was more interested in the Gregorian form, since a larger market existed with the general public.

At first ((5), p. 318) Herschel's work was that of a gifted amateur, but by his great perseverance he attained an acknowledged superiority that was attested by his wonderful discoveries. After many trials of both forms of the reflecting telescopes he decided in favour of the Newtonian form and in 1795 he had made as many as 200 mirrors of about 6·5 in. (16½ cm.), 150 of about 8·8 in. (22½ cm.) and 80 of about 18·7 in. (47½ cm.) diameter. As his fame spread, he sold Newtonian reflectors of 7 ft. (about 2 m.) with 6·5 in. aperture and of 10 ft. (about 3 m.) with 8·8 in. aperture to different buyers in England and on the continent. According to Prince Troubetzkoj's statement his prices were 100 guineas for the smaller (30 guineas for the optical parts) and between 200 and 300 guineas for the larger instrument. It was advisable to buy two mirrors for the instrument in order that one could be used whilst the other was being repolished. In the Court Collection we find a cutting from *Bell's Weekly Mess.* 10th January (1802 or later) telling us that a Herschel

* As an expert without the slightest personal claim of new discoveries in this direction, I may point out that Mr Court's unequalled collection of old catalogues has allowed us to give many details illustrating the position of the London opticians towards the house of Dollond. We are able to substantiate fully the claim of the petitioners of 1764 by reprinting divers advertisements, especially from B. Martin's lists, and unexpected light could be thrown on some business relations after the verdict in the case Dollond *v.* Champneys.—M. v. R.

reflector of 20 ft. (6 m.) focal length had been ordered for St Petersburg and the mirror was being sent back to the maker for repolishing. The money allowed by Alexander I for this purpose was 14,000 roubles (= about £2250). That is the only instance known to us of such a large instrument being sold by Herschel.

The London Institution, when it was founded in 1799, purchased a telescope from Herschel for £215; this they kept till 1874, when Warren de la Rue was the president, and then sold it. We do not know exactly the curve chosen for the large mirror. According to W. H. Steavenson's reliable statement[49] the mirrors pre-

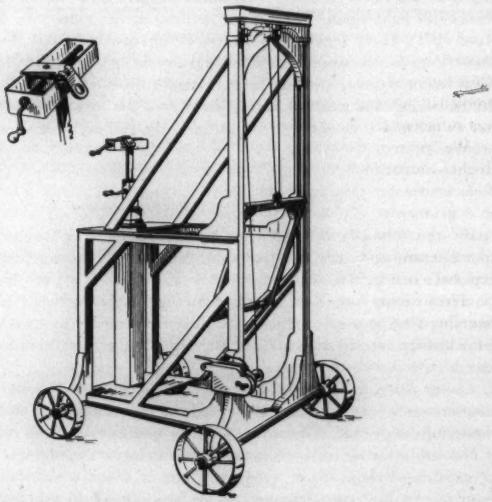


Fig. 15. Herschel's stand for Newtonian telescopes (in the Jena collection). The lateral movement also shown in some detail

served at Slough are mostly over-corrected; we may therefore assume that the surface was not parabolic but tended to a hyperbolic form. In some cases there was a certain under-correction, the parabolic form not having been attained, and in one or two cases ([49], p. 215) the surface was spherical. We must, after this, come to the conclusion that Newton's aim to produce parabolic surfaces had not been achieved by Herschel.

The eyepieces were of simple construction, single lenses in the majority of cases, and some of them of extremely short focal length. In [49], p. 216, we find enumerated nine eyepieces under 0·064 in. focal length, giving magnifications with the 7 ft. telescope of between 1300 and 7700!

The reader will be surprised that as yet only Newtonian reflectors have been mentioned as being made by Sir William Herschel and his son, but W. H. Steavenson's carefully prepared paper ((49)) leaves no room for doubt in this respect: all the Herschelian instruments sold to observatories and private individuals at home or abroad were of the Newtonian type. Herschel's own system, employing one mirror only—in a slightly inclined position—was reserved for use at Slough Observatory. This applies especially to the 20 ft. telescope with 18·7 in. aperture by means of which his most important discoveries were made. This giant telescope with 4 ft. aperture had the mirror inclined, but it was not used for regular astronomical work ((49), pp. 212–13).

The impression made in scientific circles by Herschel's discoveries was quite extraordinary. As achromatic telescopes could not then be made with apertures exceeding 5 in. (see p. 247) astronomers were constrained—in the way Newton had predicted—to have recourse to reflectors, and these were to be had in a quality that was sufficient for the demands of that period.

We cannot wonder that in France the interest was very great and de Rochon intended to have a reflector made with a platinum mirror, in order to obviate tarnishing. We hear that the Paris optician, N. S. Caroché, had actually made an instrument using that costly substance for the mirror, which is said to have had nearly 2 m. (about 7 ft.) focal length and 21½ cm. (8·4 in.) aperture. That gives the aperture ratio of 1 : 9·3, but we are not told anything as to the performance of this expensive instrument.

The example set by Herschel of selling Newtonian instruments at fair prices soon brought London artists into competition. From a catalogue of 1797 preserved in the Court Collection we learn that the firm of W. and S. Jones offered

> Reflecting telescopes fitted up either upon the Gregorian, Newtonian, or Herschelian principles with improved wood or metal stands, and other apparatus for making celestial observations in the most commodious and accurate manner.—The general prices are as follow:
> Fifteen feet (4·6 m.) in length the large metal fifteen inches (38 cm.) in diameter from 250 : 1 to 500 : 1.
> Twelve feet (3·7 m.) in length the large metal fourteen inches (35½ cm.).
> Eight feet (2·4 m.) in length the large metal eleven inches (28 cm.) and lower.
> Six feet (1·8 m.) in length the large metal nine inches (23 cm.).

William Harris, of 50, High Holborn, advertised, in 1815, reflecting telescopes upon Gregorian, Newtonian or Herschelian principles from 100 : 1 to 1000 : 1.

Neither of us knows anything as to the commercial results of such competition with Herschel as a manufacturer; the Jones house evidently tried to offer reflectors with larger apertures* than those of Herschel. Soon after Sir William Herschel's death we hear of a Herschelian telescope demonstrated by Ramage before the London Astronomical Society. The focal length was 25 ft. (7·6 m.) and the aperture

* I have seen in my time many hundreds of old Gregorians and also mirrors for the same, but only one or two over 10 in. in diameter. I do not remember seeing a 15 in. one. Pieces with 8 in. apertures are fairly common, and I have seen plenty with apertures of 6, 5 and 4 in. I do not think that many of a larger size than, say, 10 in. were made.—T. H. C.

18 in. (46 cm.), about the same as in Herschel's 20 ft. telescope. The correction was satisfactory only for 10 to 11 in. (25 to 28 cm.) diameter; apparently the quality of Herschel's work was not easily reached. A plan was discussed there to order from Ramage a reflector for Greenwich Observatory with a focal length of 55 ft. (16·8 m.) and 21 in. (53⅓ cm.) aperture. As apertures of such sizes were hardly to be had in achromatic refractors at that time, astronomers looked with favour on reflectors, and we know that in 1825 the eminent Italian optician, G. B. Amici, made Newtonian reflectors with an aperture of 12 pouces (32·5 cm. = 12·8 in.). The leading men of the Vienna Polytechnical School also recommended the construction of reflectors to their pupils, but we do not know whether such telescopes were made in Vienna nor the results by which they were attended.

It was in England that the greatest interest was taken in these instruments and we must point to the Earl of Rosse's wonderful skill and perseverance in constructing his leviathan of 6 ft. (1·8 m.) aperture. (It was actually made in Ireland.)

We shall not follow up this subject further but should like to point out that Newton's general practice with the reflectors was followed up with the greatest industry and skill, after Herschel had demonstrated practically what splendid work could be achieved.

VI. The earlier endeavours to avoid a secondary spectrum

In 1762 when A. C. Clairaut in Paris repeated Dollond's fundamental experiments, he noticed that the prismatic colours were not absolutely destroyed but that a certain uncorrected aberration still remained, which he did not consider then as very harmful. He ascribed this fault quite correctly to the fact that the proportions of the dispersions in the red, orange, etc. (the *partial* dispersions) had different values for the crown and the flint used and also differed from the proportion of the *total* dispersion for the same pair of glasses, say from red to violet. He was then unable to give any exact numbers, as nobody at that time was in a position to define exactly the border-lines between red and orange, orange and yellow, etc.

Not much later the already-mentioned Prof. R. J. Boscovich, a Jesuit father teaching natural philosophy at the university of Padua, took up the same subject for his scientific study. He devised an instrument, called a *vitrometrum*, for the purpose of investigating these residuary aberrations by looking at the short spectrum thrown on a screen by means of a pair of prisms achromatised after Dollond's plan. This spectrum is much shorter than that of a single prism, since the red part of an ordinary spectrum has been folded over the violet part, so to speak; and we can easily understand that a physicist may express himself by calling this the *secondary spectrum* belonging to this pair of prisms. We do not, however, know the name of the expert who first used this expression. The vitrometrum planned by Boscovich consisted of a glass prism combined with a water-prism acting in contrary direction, and the angle of the water-prism could be altered at will. It is easy to imagine that by means of trial and error the best colour correction of which that combination of glass and water was capable could be effected, and that in this case the secondary spectrum

should have the shortest extension. By slightly altering the water angle he was able to over-correct or under-correct a little for colour, in our modern expression, and to study the coloured margins at both ends of the secondary spectrum thrown on the screen under these circumstances. Boscovich showed his experiments in 1767 to the Duke of York (then on a journey to Italy) and even lent him his vitrometrum (see p. 238). When the instrument was returned to him, he learned that some similar contrivance had already been constructed by Hoare, a Fellow of the Royal Society, in England. (We are both unable to do more in this respect than to state the fact as given by Boscovich in 1767.) The publications of this scientist came out rather slowly, but C. Scherffer, S.J., a teacher of natural philosophy at the University of Vienna, published in 1765 a German translation of Boscovich's results and pointed out the high scientific value of his colleague's work.

Boscovich was of opinion that he could combine n rays of different colours in the same focus, when n different substances were at his disposal, and that he had only to solve a system of n linear equations. In the only case of practical importance (the n different substances being n different kinds of glass), the conclusion was incorrect, as A. König's treatment of this question in 1904 showed. The different kinds of optical glass available at that period were too uniform as regards their partial dispersion and the n linear equations were not independent of each other. In the case where he intended forming a triple objective with crown, flint and water, having a tertiary spectrum only, he was quite correct, however, as water was sufficiently different from both kinds of glass in respect of the values of partial dispersions. The solution was of small practical importance, since fluid lenses have too many drawbacks, although at that time this was not realised. The most important attempt to remove the secondary spectrum that was published in the eighteenth century was founded on the use of fluid media.

Boscovich was not in a position to calculate the radii for the surfaces forming a telescope objective without secondary spectrum, as it was impossible at that time to give the refractive index of an exactly defined colour.

In 1787, when the Scottish naval surgeon R. Blair (8) began his work of improving the colour correction of the telescope, he did not observe the secondary spectrum thrown on the screen. His instrumental resources in a place like Merchiston were small and he could not hope to achieve his object by sufficiently exact pairs of prisms that were ground and polished by a method of trial and error. He therefore decided to study the secondary spectrum of a given objective by observing the coloured fringes of the circle of confusion as the focus of the telescope was varied. He chose a very bright point as an object and employed very deep eyepieces in order to obtain fairly high magnifications for observing the image. He was able by this means to detect any residuary colour with great nicety, although he was not in a position to give any exact numerical results. He also tried to correct his trial objectives for spherical aberration by using formulae published by Huygens. He convinced himself that the ordinary designation *achromatic* implied too much, and tried to construct objectives spherically corrected as well as free from secondary colour, giving them the name of *aplanatic* objectives. By hard work extended over several years he was

able to show in his report that for fluid media of certain dispersive character (muriatic and nitric acid) the partial dispersions were extended in a peculiar way: the dispersions were arranged in a manner exactly opposite to the way to be found in other dispersive media (metallic solutions and flint glass). Using these unexpected facts he was able to do away with the secondary spectrum in an objective containing crown-glass and representatives of both classes of dispersive media (or, if both were fluid, a mixture of both). By means of his exact mode of observation he convinced himself that the tertiary spectrum remaining was so insignificant that he was unable to detect any traces of it with the means at his disposal. Blair's paper is by far the most important application of theoretical optics written upon this topic in the eighteenth century. Although he could give no numerical values for his observations, he was able to point to very remarkable and quite unexpected properties of two of his dispersive media with regard to the arrangement of the partial dispersions belonging to them. His endeavour to correct all his trial combinations for spherical aberration is also worthy of our acknowledgment. There is no doubt that his paper was at first received with great interest.

We may conclude from the patent he took out for his invention on 4th April, 1791, No. 1800*, that he attached a considerable commercial value to his idea. In fact, he tried with his son's help up to 1797, and perhaps later, to manufacture such "aplanatic" telescopes in London for sale. This agrees very well with Nicholson's statement (26) in April 1797, after which R. Blair still had hopes of bringing out his aplanatic telescopes, that Blair did not prosper and apparently he never wrote the communication he had promised for Nicholson's *Journal*. Quite apart from the corrosive action of the acids on the lenses or cells containing them, he lost sight of the striae unavoidably caused in these fluid media by changes of temperature. It is probable that the private judgment of well-known opticians (given when questioned by customers) did much harm to Blair's reputation as an optician; Nicholson's statement may be referred to with regard to this impression.

As to the acknowledgment of his discovery with regard to the partial dispersions of his two peculiar (dispersive) fluids he was remarkably unfortunate. Even after his principal paper in 1791 no notice was apparently taken of this theoretical discovery and we doubt whether its importance was duly appreciated. Later, in 1802, an authority like W. H. Wollaston strongly objected to Blair's statement. It is to be regretted that the splendid discovery of some of the dark lines in the solar spectrum was at its first announcement used by their discoverer with the object of refuting Blair's very important statement. We know to-day that Wollaston was in the wrong, because he did not use the dark lines for an exact measurement but only for a rough estimation.

Without wishing to diminish the importance of Blair's theoretical statement, we must concede that his exertions did not bear any fruit with regard to the actual improvement of the telescope.

* He also took out a patent earlier, 26th April, 1785, No. 1473.

VII. Later improvements and modifications of the achromatic telescope

Probably soon after Dollond's patent a prism combination was offered for sale by this firm for demonstrating the principal method of removing the colours of the prismatic spectrum. H. Boegehold (9) recently published the results of a thorough measurement of a specimen preserved at Utrecht. The instrument consisted of three single prisms (two of crown, one of flint-glass) turning on hinges; they could be combined differently, the combination of the flint with the larger crown prism giving practically no deviation of the beam but primary colour aberrations, the combination of all three prisms giving a decided deviation without primary colours (only secondary colour aberrations appearing).

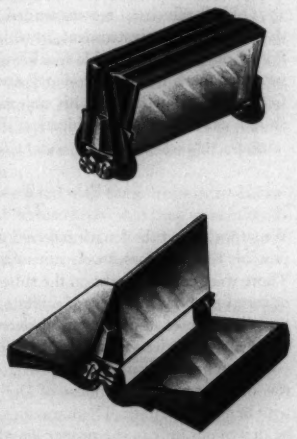


Fig. 16. H. Boegehold's reproduction of Dollond's triple prism

We know from different sources that such demonstration prisms were regularly sold in the eighteenth century; their descriptions are in the best agreement with the specimen recently measured. It is worth while noting that every one of the prisms, especially the two crown prisms, were found quite full of striae.

We must suppose that after 1766, when the verdict had been given in P. Dollond's favour, London opticians were deterred from making improvements in the achromatic telescope until the patent expired in 1772. The telescopes at that time were made with vellum draw-tubes and had often a coat of nurse skin on the outer tube (see also Figs. 13 and 14); quite a number of these pieces have been preserved. We are impressed by their favourable outward appearance and their usefulness as optical instruments after so long a period. It is possible that in the beginning a number of the larger instruments were made with rigid brass tubes which could readily be screwed together for use. One of these specimens (of about 6 ft. total length) is preserved in the Berlin Hohenzollern Museum; it had been bought for and used by Frederick the Great.

An optical improvement of the objective was described by P. Dollond early in 1765. Whereas J. Dollond had made his telescopes with binary objectives only (the three-lens forms being reserved for objectives of opera glasses), his son brought out a telescope of $3\frac{1}{2}$ ft. focal length bearing a triple objective of $3\frac{3}{4}$ in. clear aperture and an aperture ratio of 1 : 11·2. It was a large aperture ratio for an objective of this focal length, and he observed that specially great care had been taken with the

figuring of the surfaces. The diameter of $3\frac{3}{4}$ in. (9·5 cm.) was considered then as something very remarkable. We may mention here that this triple-lens construction was generally considered as a great improvement over the older binary lens. Details of different specimens, after the two formulae have been put to the test of trigonometrical calculation, may be found in (39). An inspection of the different graphs provides all the information possible to-day, so that we may leave this matter there.

About the time of the first introduction of this triple objective, more exactly in 1771, H. Pyefinch (20) recommended a peculiar telescope. We must describe it to-day as a pancratic instrument, in which the size of the image was varied by employing an objective of variable focal length. If we combine the contents of his patent with a remark in his price-list (between 1770 and 1780) preserved in the Court Collection, we gather that his object-glass was planned as a lens system which we should call to-day a tele-objective. The remark is as follows:

Refracting telescopes for sea and land, with achromatic moving object-glasses:

3–20 in.	£1	11	6.
Two feet	£2	2	0.
Three feet	£3	3	0.

We suppose that the length referred to the longest distance the tubes allowed. It is possible that the glasses were not sold before the Dollond patent had expired (1772). There were certain marks on the tube corresponding to certain distinct focal lengths or magnifications in order to facilitate the setting of the instrument. Needless to say, the diameter of the exit pupil decreased with the magnification; consequently some magnifications could not be used in unfavourable weather.

A much more important improvement, as far as the general public was concerned, was brought out by the house of Dollond about 1783 when it advertised telescopes with brass draw-tubes. There was an arrangement which permitted the brass tubes to be drawn out only to the proper length, but any one of the vellum draw-tubes easily became detached from the holding tube if handled carelessly. (A loss of time was the undesired consequence.) The invention* had been patented in 1782 by J. L. Martin, the son of the well-known optician, and it is said that the Dollond house bought the patent from him. As yet nothing definite is known in this respect; we can only point out that in 1784 John Jones advertised "The new improv'd (achromatic telescopes) with brass tubes by which an instantaneous view of the object is presented, and shuts up very conveniently for the pocket, of various lengths, without stands," from £2. 2*s*. 0*d*. to £8. 8*s*. 0*d*.

George Adams had a similar advertisement in 1787 (when the patent was possibly still valid) as follows: "Acromatic telescopes with brass drawers, which may be drawn out at once, and that shut up conveniently for the pocket," from £1. 11*s*. 6*d*. to £13. 13*s*. 0*d*.

Returning to P. Dollond, we have in the meantime found one of his first advertisements preserved in the British Museum. It seems somewhat older than the

* We must, however, point to the fact that J. L. Martin's patent (24) was restricted to *plated* draw-tubes. It appears probable that simple brass tubes were used somewhat earlier, so that neither Jones nor Adams infringed Martin's patent.

specimen with the French text reproduced on p. 120 in (40). In the older form he does not give the short price-list appended later, neither does he call them *military* telescopes.

In 1800 (30th May, Patent No. 2407) D. Adams (1) tried to improve the arrangement of such brass draw-tubes with a view to making the telescope more compact when shut. By a happy coincidence we can give details* as to prices and discount. We may point out that according to the closing sentence telescopes with single objectives were being sold even after 1800. These prices for telescopes with brass draw-tubes seem very low, and we doubt if the business done was remunerative.

In any case it was a very great improvement with regard to durability and portability, especially for military purposes, where the instruments were often exposed to very rough handling. We may mention here that for more than 100 years the brass draw-tubes determined the form of the terrestrial telescope; they were replaced from 1893 by the more compact arrangement of the Jena prism glasses provided with Porro prisms.

We have already observed that telescopes provided with these brass draw-tubes were soon advertised by other London opticians; we also know that they were offered as early as 1785 by J. H. Tiedemann, the Stuttgart optician. It is too early to give an account of the way in which this invention was introduced to the optical world;

* Written on the back of a large shop print by Dudley Adams, brother of George Adams the younger. Its date is shortly after 1800. I have been very careful in copying this unique document. It was sold in a collection of shop prints (at a London auction room) and it is to be noted that although this collection contained over 600 varieties, it included only two opticians and I have both of these in my collection.

"A Private Invoice Book

Comprising different Descriptions or Classes of Telescopes may (one or the other of them) with propriety accompany any assortment of Goods.

The same being selected as applicable to General Demand & Intended for the information of the Mercantile & Shipping interests to whose particular & attentive Consideration this trifel is most respectfully submitted.

Adams Patent Telescopes

rendered considerably more portable than any hitherto made these are particularly adapted to the use of the Military office viz

				£	s.	d.		Discount deducted		
12 One foot	4 inches	when shut	42/- each or	25	4	0	per doz.	18	18	0
12 Eighteen in.	4¼	do.	do. 63/- do.	,, 37	16	0	,, ,,	28	7	0
12 Two feet	5¼	do.	do. 84/- do.	,, 50	8	0	,, ,,	37	16	0
6 Three feet	7½	do.	do. 115/6 do.	,, 34	13	0	,, ½ ,,	25	19	0
				148	1	0		111	0	0

Profit to the Merchant 37. 0. 3 (*sic*).

N.B. The above will be contained in a packing case

length 2 feet 1¾ Inches
width 8¾ ,,
height-depth 9¼ ,, Weight 60 lbs.

N.B. The whole of these telescopes though put down at low prices & a great Discount is allowed on them are never the less Warranted by Mr. Adams House to be glassed on the best & most perfect principles. The object glasses not being single but Achromatic."—T. H. C.

perhaps another student of optical history will fill the gaps we must unwillingly leave. It is hardly necessary to mention that even in England, and certainly on the Continent, vellum draw-tubes still continued to be made, especially for instruments

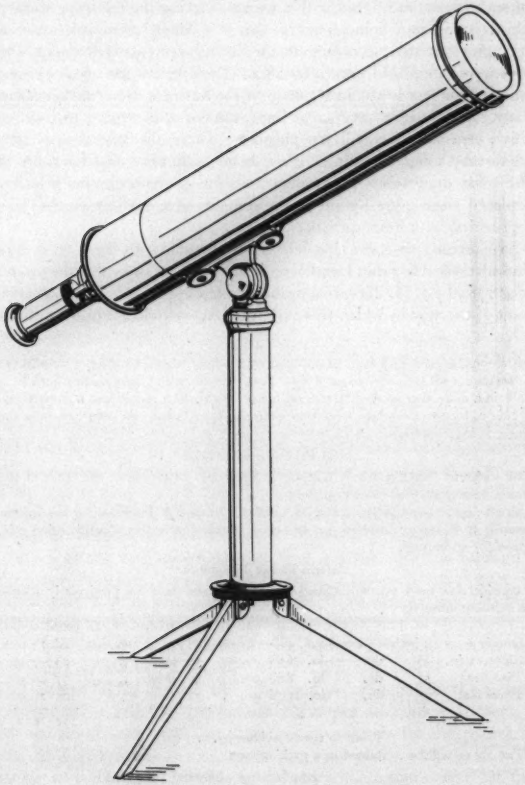


Fig. 17. P. Dollond's compact telescope ready for use

of lower price. This conclusion is well substantiated by D. Adams' patent of 1815 (a), where elaborate machinery is described for making improved cardboard tubes.

We are unable to point out any real improvements during the latter part of the eighteenth century; we may mention an ingeniously devised stand for a small telescope which we find in a list brought out between 1790 and 1793 by William

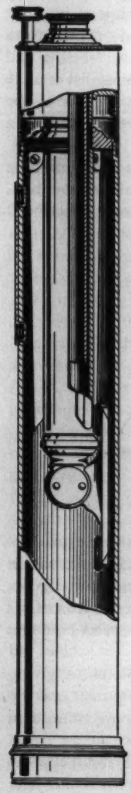


Fig. 18. P. Dollond's compact telescope ready for travelling

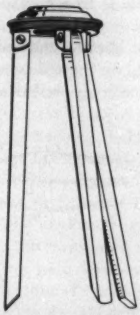


Fig. 19. P. Dollond's folding stand ready for packing

Fig. 20. P. Dollond's pillar with rest-piece ready for packing

Fig. 21. Dollond's and Fraunhofer's Galilean glasses about 1825

and Samuel Jones: "An improved portable 7 inch achromatic telescope in brass with a stand that packs up into the tube of the telescope, adapted for astronomical uses," £3. 13*s*. 6*d*. This example shows that London opticians catered for a public

given to luxury, but nobody will ascribe to this arrangement any considerable technical value.

But we must not omit to mention the very pretty single opera glasses put on the London market. Especially after W. Worris' invention, patented in 1804, very pleasing glasses with many small draw-tubes were made that would shut up in a very small compass. There is a splendidly preserved specimen of Dollond's manufacture in the Jena Collection, and the six gilt draw-tubes are quite as serviceable and well fitting to-day as they were when that piece was sold. From a price-list of 1829 we may give the date of this specimen as somewhere in the first quarter of the nineteenth century. We may conclude from this also that there was in London a good market for luxurious articles.

Although C. Varley (50) did not improve the ordinary telescope when bringing out his graphic telescope in 1811, we must devote some space to this invention. It was a drawing instrument exceedingly well designed and we may describe it

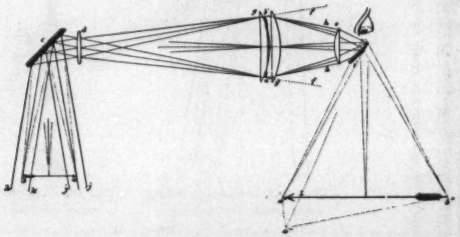


Fig. 22. C. Varley's graphic telescope (patented) after his later description (51) of 1836

better by saying that it allowed the user to obtain the results for which to-day we should employ a tele-objective. Although this instrument does not fall quite within our scope, the whole description is so lucid, full of exact observations, and given with such an evident enjoyment of the invention, that we must refer to it here. It ought to be treated more fully in the history of the camera obscura and camera lucida.

In working out this invention, Varley tried to improve the eyepieces (52), giving them a larger distinct field free from distortion. The whole development was by trial and error and without any of the mathematical foundation we admire in G. B. Airy's case.

P. Dollond's house justly enjoyed a very high repute for telescopes, and it appears as if in the last years of the eighteenth century J. Ramsden was the only maker who was of comparable worth. It is possible that towards the last decade of the eighteenth century both brothers-in-law had some differences either on personal or optical matters, as we have already hinted when considering the Chester Moor Hall controversy in Section IV A. We have from (39) a fairly exact knowledge of Ramsden's

telescopes and must especially allude to their excellent colour correction, which speaks well for the judgment and experience of these old masters. For it ought to be understood that the good work turned out in these old times was the consequence of the talents and education of the master, a personal gift that could not be transferred to the successor, as we may conclude from the fact that neither J. Short nor J. Ramsden could be replaced after their demise.

In fully acknowledging great talents within the optical brotherhood, we are bound to mention here also an unpleasant disposition not unknown among that community. Some of them appear to have over-estimated their own technical knowledge and they showed great aversion to accepting the help of scientific men. As evidence for this we may not only point to the blameworthy manner in which the well-known optician W. Jones attacked W. H. Wollaston because he dared to recommend an improvement not approved by Jones, but we must also recall that P. Dollond took the liberty of changing the curves for the periscopic glasses, although the description in Wollaston's patent was quite clear. When developing his splendidly planned trifocal spectacles J. I. Hawkins had unpleasant encounters with London opticians, and an invention like G. B. Airy's first astigmatic spectacles was applied earlier in the United States than in London. Neither did the eyepieces calculated by the same authority find greater favour with the optical masters in London. On the whole it must be deplored that such splendid scientific work was disregarded at a time when scientists of such standing as Fraunhofer, Stampfer, Amici, Schleiermacher and others were devoting their time to the improvement of optical manufacture abroad. The time of the master optician was coming to a close.

We are happy to point here to the old report of a Thüringian scientist, who made J. Ramsden's acquaintance on a scientific visit to London. Although its contents are not of the very first importance, it gives an interesting view of that famous workshop and shows the difficulties in obtaining good optical glass. It is a pity the account was not written much earlier; as it is, some of its statements are rather vague. But other parts may be more reliable, for it is not probable that a Thüringian official would be aware of an English excise duty on glass, nor of the possibility of obtaining a remission for optical glass by laying a petition before Parliament, unless he had been told by a person fully acquainted with such things, which were not common knowledge. We therefore look upon Sulzer's narrative as trustworthy in the main.

This glass problem, unsolved in the eighteenth century, was the principal reason for the fact that the London opticians were, optically speaking, not in such a thriving state as we should have expected after J. Dollond's technical achievements. Fortunately we have in the well-instructed amateur W. Kitchiner (21) an important and impartial witness for the state of optics in the period covering the beginning of the new century. Not only could the modest aperture of 5 in. (12½ cm.) of Dollond's largest achromatic tube not be repeated, but the scarcity of good glass was so universally felt that opticians were forced to abandon the triple lenses in favour of binary systems, although they realised this to be a retrograde step. We know to-day—and we may refer the reader to (39)—that it was not the binary system as such that was

to blame for the aberration, but its faulty arrangement; with proper curves the binary system leaves nothing to be desired in the correction of spherical aberration. But although some of the leading London opticians of that time (e.g. W. Jones) had a great opinion of their own erudition, none of them appears to have worked out a better formula. The military telescopes of that warlike period could be sold successfully since their objectives had only moderate focal lengths and diameters; but in telescopes destined for astronomical observation no remarkable improvements were made, as will be seen in the price-lists reproduced by W. Kitchiner.

The need of optical glass was strongly felt and some large prices for making flint glass were offered, but no expert in glass making attempted to secure them. The reason for this strange indifference may be found in the fact that the demand even of the greatest London establishment was not large enough to induce the glass makers to undertake the experimental work entailed and to reserve plant solely for the production of optical glass.

We cannot now decide whether a joint effort of all the important optical manufacturers in London could have offered a sufficiently hopeful outlook to such a glass producer, and we are fully aware of the difficulty of convincing a number of independent (and jealous) masters of the necessity of such a coalition. If we trust to Sulzer's statement, some small beginning towards a combined action was actually made in so far as some ineffectual trials were initiated, not only to obtain somewhat better flint glass but also to get a remission of the glass excise for such a particular flint melting. One of us did his utmost in the spring of 1927 to discover such an Act of Parliament, but, for the time before 1790, found none. Perhaps somebody else will be more successful in the search.

As far as we are aware, nothing was done in respect to the glass question during the end of the eighteenth century: the wholly unsatisfactory state of the glass market was known to the technical experts, but, as nobody within their horizon achieved more—the repeated exertions in France were futile without exception—they apparently did not take any great trouble in this respect.

So it came to pass that the strenuous exertions at Benediktbeurn, which commenced in 1805 and continued with increasing energy and success from 1809, completely escaped the attention of English experts. They apparently did not become known much before W. Struve's enthusiastic report of the Dorpat refractor in 1824–5. The English experts, it is true, had come into contact with P. L. Guinand a little earlier, but he died in February 1824 before anything had been settled definitely as to the erection of a factory in England. That is why the energetic effort in the 'twenties to make optical glass under M. Faraday's lead was undertaken too late. And as the secret of the method of stirring was not discovered, the results, although of considerable scientific interest, were not of practical importance. That is undoubtedly the reason why the London opticians could not compete with Fraunhofer in the manufacture of larger telescopes. There were too many advantages on his side. Also a new era of optical production was dawning; the time of a centralised industry directed on scientific lines; command over a well-conducted factory of optical glass; highly effective scientific and technical prepara-

tions; drilling of the workmen only to execute given formulae by means of a cleverly planned division of labour: all these were Fraunhofer's aims and by these means he was able not only to replace, but even to overcome the accumulated experience of the London master workman.

The London opticians did not give in without fighting. The elder Tulley undertook the construction of an astronomical objective with an aperture of $7\frac{1}{4}$ in. ($18\frac{1}{4}$ cm.) using a piece of flint-glass sent in by Guinand. We must acknowledge the pains he took, especially as the original crown-glass piece turned out useless and had to be replaced by a second one, but it is not probable that under such circumstances the result could be compared with an objective planned in Fraunhofer's wonderful way. Similar lenses could not be made in London at that time as discs of such diameter were unobtainable. The great difficulties under which the manufacturers of large achromatic telescopes were labouring have been explained in a comprehensive manner by W. Simms (44) in 1849, and we must refer the reader to his paper.

Although an acknowledged authority like Sir John F. W. Herschel knew and esteemed Fraunhofer personally, it does not appear that his contemporary scientists in England really appreciated the improvements gained in and secured for the Optical Institute in Munich. Thus J. South continued to order large instruments from R. A. Cauchoix in Paris. It is very awkward for us to give a judgment, especially as one of us cannot be considered altogether impartial. We must at least own the possibility of a mistake on South's part in so far as the great refractor of the Paris Observatory is concerned. He admired it as an optical masterpiece, but we know from unimpeachable witnesses—the Paris astronomer Le Verrier and the Paris optician Lerebours—that the instrument in question was considered decidedly poor in 1854. In this case we are quite safe in declaring that this instrument could not be compared with Fraunhofer's achievements in the same direction.

Much later than in Fraunhofer's lifetime, in 1841, G. Jeans (19) gave very interesting details as to large achromatic objectives finished by R. A. Cauchoix and sold to England. As this artisan retired about 1836, the actual date of sale must have been earlier. We subjoin the following list derived from the source mentioned; we have taken the numbers to mean inches, not pouces.

Proprietor	Focal length (ft.)	(m.)	Aperture (in.)	(cm.)	Aperture ratio
E. J. Cooper	25	7·6	14	$35\frac{1}{2}$	1 : 21·4
Duke of Northumberland's present to Cambridge	20	6·1	nearly 12	$30\frac{1}{2}$	1 : 20·0
J. South	19	5·8	11·9	30	1 : 19·4

In Edinburgh alone at that time the director of the Observatory decided to give a trial to the new optical expert and ordered a medium-sized refractor from Fraunhofer in Munich. We are happy to be able to publish the following important part of the correspondence which has been saved by a fortunate combination of circumstances:

À Monsieur le Chevalier Schumacher à Altona.

Monsieur, 1 *Juillet*, 1825.

Il y a un an que vous avez commandé pour Mr. le Professeur Lesli une lunette achromatique de 8 pieds de foyer et de 70 lignes d'ouverture avec pied etc. Par votre lettre du 11 de Juin vous annulez cette commission et vous commandez une lunette méridienne de la même grandeur pour l'observatoire d'Edimbourg. Ayant commencé aussitôt la lunette pour Mr. Lesli; comme vous avez désiré, et ayant négligé d'autres commissions vous concevez facilement que cela est du moins bien désagréable pour moi d'avoir perdu mon temps. C'est pourquoi je vous prie de me dispenser, pour l'avenir, des commissions qui ne sont pas tout à fait sûres. Une lunette avec pied étant souvent recherchée j'accepte l'annulation de la dite commission; mais pour la lunette méridienne, si elle est commencée, je ne pourrais accepter une annulation, parce qu'un instrument de la même dimension n'est, peut-être, jamais recherché. Je vous prie donc de prendre vos mesures en conséquence. Je vous enverrai la grande lunette méridienne, lorsqu'elle sera finie et je vous prierai de la faire passer à Edimbourg.

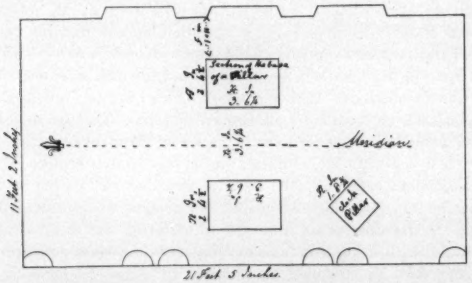


Fig. 23. Ground plan of the transit room of the Edinburgh Observatory

Vous m'avez envoyé le dessin avec les dimensions des piliers de pierre sur lesquels l'axe de la grande lunette méridienne doit être placé. Je suis de l'avis que la distance des deux piliers est trop petite, c.-à-d. que l'axe horizontal de la lunette serait trop court pour un instrument de cette dimension, et qu'on trouverait des changements considérables dans la direction de l'axe. Je suis donc de l'avis qu'il est nécessaire, si le bâtiment le permet, de placer les piliers à une distance plus grande. Le dessin ci-joint montre le rapport des dimensions de différentes pièces de cette grande lunette méridienne comme je la construirai si la distance des piliers ne m'en empêche pas. Ayez donc la bonté de m'écrire s'il est permis de faire un long axe convenable; ou s'il faut, que je le fasse court!

Il est vrai, que la flexibilité des tuyaux de la lunette qui sont de laiton, ne nuirait point, si ces tuyeaux par leur poid ne se plient qu'en sens vertical; mais quand le laiton n'a pas partout la même épaisseur ou la même élasticité dont on ne peut s'assurer, les tuyaux changeraient aussi un peu en azimuth. C'est pourquoi je ferai un contre poids pour chacune des deux moitiés de la lunette. L'axe sera séparément contrebalancé comme le dessin le montre.

Pour qu'on puisse observer des petites étoiles qui disparaissent au champ éclairé de la lunette, et pour l'observation de petites comètes je ferai l'éclairage de manière qu'on puisse en éclairer les fils mêmes au champ obscur, ou éclairer le champ.

Je ferai 5 fils verticaux au champ de la lunette. Je vous prie de me mander quelle distance on voudrait que je leur donnasse? Ordinairement on fait cette distance équatoriale de 15″ en temps; mais quelquefois on l'aime plus petite ou plus grande.

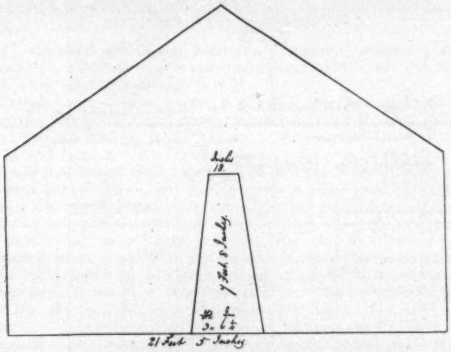


Fig. 24. Vertical section of transit room through one of the pillars which support the transit instrument and in the plane of the meridian

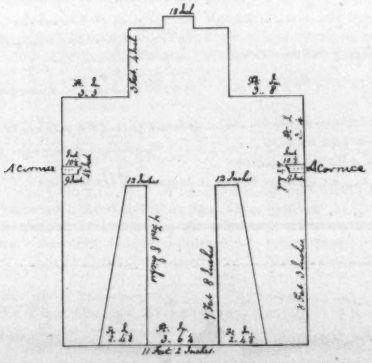


Fig. 25. Vertical section of transit room perpendicular to the meridian

In order to give an idea of Fraunhofer's superiority we may mention here that in his answer of February 1825 he offered in addition to other instruments a refractor of 18 pouces (49 cm. = 19·2 in.) diameter! Unfortunately the funds at disposal in Edinburgh were not sufficient to order such a giant instrument.

We do not know even whether the much smaller instrument chosen was ever delivered in Edinburgh, for Fraunhofer's fatal illness intervened. Unfortunately

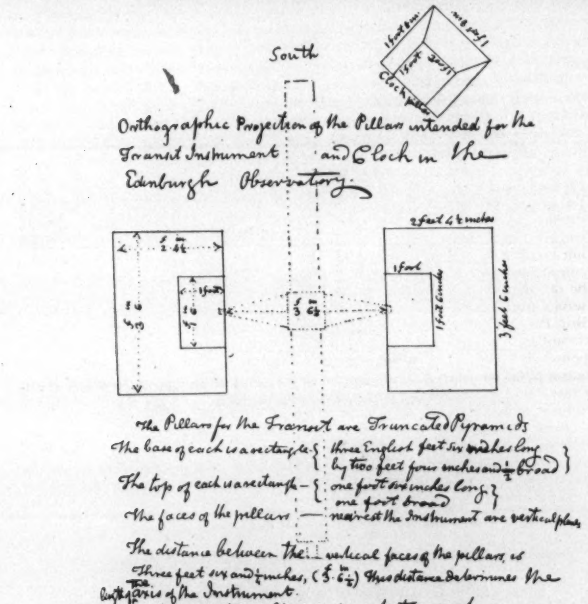

South
Orthographic Projection of the Pillars intended for the Transit Instrument and Clock in the Edinburgh Observatory.
2 feet 6½ inches
1 foot
1 foot 6 inches
3 feet 6 inches
The Pillars for the Transit are Truncated Pyramids
The base of each is a rectangle { three English feet six inches long by two feet four inches and ½ broad }
The top of each is a rectangle { one foot six inches long one foot broad }
The faces of the pillars nearest the Instrument are vertical planes
The distance between the vertical faces of the pillars is three feet six and ½ inches, (3′ 6½″) this distance determines the length of the Instrument.
The height of the pillars is seven feet one inches.

Fig. 26. Relating to the order from Edinburgh Observatory

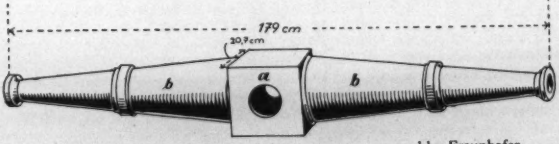


Fig. 27. Axial part for the transit instrument as proposed by Fraunhofer

the necessary time was not allowed to the Optical Institute at Munich, as its leader was prevented by death from seeing his plans fulfilled and he was unable to educate the competent successor he had chosen. When Fraunhofer died, the work lost its master mind, and it is only due to the lack of competition that this state of things did not become apparent to all.

We shall finish here and leave to some future occasion the account of the development of the telescope in England after the years 1826–30.

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(39) ROHR, M. VON. "Fraunhofer's work and its present-day significance." (17th July, 1926.) *Trans. Opt. Soc.* **27** 1925–6 (277–92); 16 figs. [242, 246, 247.]

(40) —— "Contributions to the history of English opticians in the first half of the nineteenth century (with special reference to spectacle history)." (12th May, 1927.) *Trans. Opt. Soc.* **28** 1926–7 (117–44); 20 figs. [243.]

(41) —— See under (11).

(42) SCHYRLE, A. M. v. See *Trans. Opt. Soc.* **25** 1923–24 (70), under (50). [213.]

(43) SHORT, J. "A method of working the object glasses of refracting telescopes truly spherical." (Paper delivered sealed up 30th April, 1752, read 25th Jan. 1770.) *Phil. Trans.* **59** 1769 (507–11). [217.]

(44) SIMMS, W. See *Trans. Opt. Soc.* **28** 1926–7 (143 under (63)). [249.]

(45) SMETHWICK, FR. "A new and perfect way to grind opticke glasses in figures that are not spherical, which will add much to the use of perspective glasses by sea and by land, as well as for the heavens, because his are all open and soe shew the object clearer as admitting more sight, whereas the spherical which are hitherto made

must be coverd for the most part, and will also, in reading or magnifying glasses, now commonly called microscopes, shew all things in more distinct and in truer proportions; in burning glasses will fire more strongly, and discover in the darke at much greater distance." Brit. Pat. No. 149 (14th May, 1666).

(46) SMITH, CALEB. "A new method of improving and perfecting catadioptrical telescopes, by forming the speculums of glass instead of metal." (5th April, 1739.) *Phil. Trans.* abridged **8** 1732–44 (113–20); 3 figs. (Publ. Jan. 1740.) [223.]

(47) SMITH, JAMES. "The Mechanic"; or compendium of practical inventions; containing two hundred and fifteen articles, selected and original, arranged under the following heads:

I. Manufactures and Trade,

II. Philosophical apparatus and the fine Arts,

III. Rural and domestic Economy, and Miscellanies. Illustrated by One hundred and eight copperplate Engravings; with a copious analytical index. Vol. II. London: Caxton Press by Henry Fisher, June, 1822. Pp. 72, 8° (contains list of old papers).

(48) SOUTH, J. See "Discoveries with the great Rosse telescope." *Ill. Lond. News*, 19th April, 1845 (253–4); 4 figs. [219.]

(49) STEAVENSON, W. H. "A peep into Herschel's workshop." (15th Jan. 1925.) *Trans. Opt. Soc.* **26** 1924–5 (210–20); 12 figs. [236, 237.]

(50) VARLEY, C. "A new construction of a telescope or optical instrument for viewing distant objects, and for other useful purposes, with a suitable table or stand for the same." Brit. Pat. No. 3430 (5th April, 1811; sealed 4th June). [246.]

(51) —— "Description of his graphic telescope and microscope, by which the most distant views, or the nearest objects, may be traced of any required size." *Trans. Soc. Arts*, **50** 1836 (120–39); 2 woodcuts, table, and 23 figs. [246.]

(52) —— "One eye-piece for telescopes and microscopes." *Trans. Soc. Arts*, **51** 1837 (189–224); with 24 figs. [246.]

(53) VERITAS. "On the invention of achromatic glasses." *Gent. Mag.* **60** 1790 (890–1). [233.]

(54) WILLIAMS, —. "On an early telescope made by Guiseppe (*sic*) Campani of Rome." Meeting of Royal Astronomical Society, 13th May, 1870 (129–30). [212.]

(55) YOUNG, TH. Lect. XL. "On the history of optics." (Pp. 472–82; see p. 478.) [235.]

DISCUSSION

Mr D. Baxandall: I should like to congratulate the authors of this paper, in which many interesting facts and deductions have been brought forward. With regard to the system which James Short adopted in numbering his telescopes, the interpretation which I gave was based on an examination of the numbers on some eight examples, three of which (with apertures of 2·5, 4·4, and 9·3 inches respectively) are in the Science Museum and bear the numbers $\frac{2\,4\,4}{1\,0\,6\,3} = 9{\cdot}6$, $\frac{1\,1\,2}{1\,1\,8} = 24$, and $\frac{6}{1\,3\,4\,8} = 49$. I was indebted to Mr Court for several of the other numbers, including those on his example, which was also dated 1744. The only other dated example which I know is the Macclesfield-Huggins example belonging to Prof. Newall, which is numbered $\frac{3}{8\,1\,\frac{1}{2}} = 37$, and bears the date 1741.

I am glad to see in the list given by Mr Court other sets of numbers, to which I can add only one other, viz. $\frac{1\,8\,0}{1\,1\,8} = 9{\cdot}4$. Unfortunately for my interpretation, I notice two examples in Mr Court's list which bear the same denominator. I can only hope that in one case either the maker or Mr Court has inadvertently made a slip.

The price list of Short's telescopes was reprinted in the *Nautical Almanac* (1787), *Rees' Cyclopaedia* (1819), and by Dr Kitchiner in 1815 and later.

Prof. A. F. C. Pollard: The authors are much to be congratulated on this their latest contribution to the history of optical instruments. This scholarly paper on the telescope will require careful reading, but Dr Clay's clear résumé has held us spellbound. I must confess to a feeling of envy towards anyone who has the opportunities to delve into the accumulated mass of Mr Court's knowledge and material.

As we have heard, the earliest instruments were constructed of such materials as wood, paper and vellum. The vellum surfaced draw-tubes of Mr Whipple's telescope, so perfectly cleaned by Mr Court, move over one another in a manner which indicates wonderfully careful workmanship. Later, however, metal was introduced in the tubular parts of optical instruments with the advent of the drawn brass tube.

The construction of metal tubing must have preceded the drawing of metal tube, but I have not been able to find when metal tubing was first drawn. It would be interesting to know when this took place and if the development of the optical instrument was responsible for the important industrial process of to-day. It is certain that the drawn tube was an outstanding factor in the development of the mechanical design of the tubular instruments.

Can Mr Court enlighten us on this point?

Mr R. S. Whipple: I join in congratulating Prof. von Rohr and Mr Court on the amount of interesting matter they had been able to include in their paper, the result of much patient research spread over many years. It is, I feel, a paper which will be referred to for many years to come.

A few weeks ago I saw the collection of old scientific instruments at the Cape of Good Hope Observatory, and amongst other exhibits there was a speculum mirror made by Herschel, which had been presented to the Observatory by Admiral Maclear. This collection may perhaps form the nucleus for a collection of old scientific instruments in South Africa.

It is largely due to the efforts of Mr Baxandall and Mr Court that the exhibition of instruments at South Kensington is so complete, and the community owes these gentlemen a debt of gratitude.

Mr W. H. Towns: I join in appreciation of the work of Mr Court and Prof. von Rohr and in the thanks to Dr Clay. I am particularly interested in the paper, having been associated for a number of years with the late Mr Clarkson in the manufacture of telescopes. Referring to the question of Prof. Pollard as to the date of the introduction of drawn brazed tubing, it was a tradition in the firm that early in his business career Mr Clarkson acquired the draw bench used by Tully. This would suggest a date prior to 1850. (Incidentally the firm was the first to draw aluminium tube successfully.) The draw bench is still in use in the workshops of Messrs Broadhurst, Clarkson and Co.

Mr T. Smith: I have been much interested in listening to Dr Clay's extracts from this paper, and should like to say a word on one of the points he has mentioned. It is easy for us to misjudge some of these early opticians for not appreciating at once the outstanding advantages of achromatic objectives. We have to beware of

passing judgment in the light of our own later experience. We must remember that the dimensions of instruments had been arranged to minimise the inconvenience due to colour, so that the improvement would not be as noticeable as that between corrected and uncorrected telescopes of the dimensions we are now in the habit of using. A more subtle factor may have been the experience of opticians with the uncorrected telescope, leading them unconsciously to form the habit of concentrating attention on the well-defined part of the image alone. A modern parallel may help us to appreciate this. Visitors to an Observatory are often much impressed on taking their first look through a large telescope with the blue halo around star images: the astronomer on the other hand hardly appreciates that the halo is there because he is definitely looking for something else. What we see is very frequently what we are looking for and our failure to see anything does not always imply its absence.

All those who have been following the most interesting series of papers to which the present paper belongs must have been impressed with the great labour involved in recovering some knowledge of the history of optical manufacture in the period covered, knowledge which had almost finally eluded us and has only been preserved by several pieces of good fortune—entirely unmerited by nearly all of us—of which Mr Court's great interest in optical instruments is an excellent example. We realise now that events in the past, though not at the time thought of sufficient importance to be fully chronicled, are in fact of interest and significance. With this awakened apprehension of the need for proper records, it is not unimportant for us to consider whether we are doing our part in leaving to those who come after us an easier task, should they wish to understand the evolution of the present-day industry, than that accomplished by the authors of this paper. I suggest that the last thirty years will come to be recognised as a very important period in the history of the optical industry. Rapid progress has been made, notable experiments, both successful and unsuccessful, have been carried out, and nearly all of the knowledge that has been gained is in danger of being lost because it is not properly recorded. Evidence is not wanting that practice often runs in cycles, a process which had at one time been abandoned finding favour again at a later time. The course of events, as I can appreciate from my very partial knowledge of them, has been such that the future historian may easily be seriously misled if his information is scanty. I therefore suggest—and I believe it would at least be of as much value to present-day workers as to the historian in the somewhat remote future—that an effort should be made to place on record some of the work that has been done within the industry in the first quarter of this century. If any restriction must be made, I think it would be as much a mistake to exclude from the record all experiments that have failed as to delete all indication of what is now considered good practice. The construction of such a record would be one of the happiest ways of signalising our appreciation of these historical papers based on the Court Collection.

Prof. L. C. Martin: In expressing my keen appreciation of this charming paper I should like to ask if the authors can tell me the origin of the two-lens astro-

nomical eyepiece. I suppose it must have developed independently of Rheita's three-lens erecting system?

The President (Mr F. Twyman): I should like to emphasise the importance of the analogy which Mr Smith has drawn between the opticians of past times and those of the present. Mr Smith has pointed out how fragmentary is the evidence we possess for the manufacturing procedure of past times.

The records and instruments, part of which the Optical Society has the good fortune to see this evening, are in great part those of manufacturers who did not describe their wares, or design their instruments, for the purpose of informing posterity of the mode of manufacture. The same is the case to-day. The modes of optical polishing, of preparing the polishers, and so forth, in vogue in any particular workshop, may appear to the observer a ritual that has been handed down with but small modifications during the past few centuries, and so indeed it may be to a certain extent; but there are refinements of technique which have doubtless been discovered by individual workers again and again, and will, failing an adequate record, have to be rediscovered again and again.

I ask the Secretary to bring to the notice of the Council the suggestion of Mr Smith that an account of some of the manufacturing processes in use by optical manufacturers to-day might provide suitable material for one or more of the meetings of the Society.

I must express the extent to which I am surprised to learn, as I do now for the first time, of the wonderful fund of information and collection of instruments which Mr Court has collected as a result of many years' search, and I am sure members will appreciate the opportunity which has been given them, with the aid of Dr von Rohr's masterly handling of the material, of making the acquaintance of this wonderful collection.

Mr T. H. Court (communicated): In reply to Prof. Pollard's question, the method of drawing tubes was certainly known by 1782, for in that year Joshua Lovell Martin took out a patent (No. 1316) for "a new invented art of drawing tubes, plated or otherwise covered with silver or gold, on copper or other metal, for the purpose and construction of Telescopes... etc." It is obvious from the wording of the patent that the draw bench was already in existence and it was no doubt invented for drawing metal rods and wires—and it seems probable that the tubes used by Cuff Martin and others for their telescopes and microscopes when made of brass were drawn tubes. A critical examination of the instruments in the Science Museum should enable this interesting point to be determined.

In reply to Dr Martin, it was Kepler of course who described the first erecting telescope with an ocular consisting of two separated convex lenses. Rheita obtained a clearer image by the use of two lenses in the erecting system. Campani almost certainly added the field lens to the ocular of the microscope and may therefore have used this type of eyepiece for the astronomical telescopes for which he was so famous. I have seen several early telescopes in which the front lens of the erecting system could be removed, leaving an astronomical telescope with a two-lens eyepiece.

And, lastly, Huygens calculated the relation between the focal lengths and the separation of the lenses and reduced the spherical aberration to a minimum.

In conclusion, I should like to thank Mr R. S. Whipple for the loan as an exhibit of his fine nineteenth-century telescope and Dr R. S. Clay for so ably reading this paper and for allowing us unrestricted use of his large specialised library of early scientific and optical books.

Prof. von Rohr (communicated): Both Mr Court and I are fully aware that there are many gaps in our paper and shall be only too glad if some of them are filled.

Mr Baxandall has kindly given us the *Nautical Almanac* of 1787 as a new source of reference. Dr Schröder was evidently in possession of a genuine old list by Short but unfortunately did not publish it as a whole.

Mr T. Smith's opinion in favour of the old English opticians like J. Ayscough, who did not introduce the achromatic glasses although they had a very early knowledge of them, ought to be accepted. It seems as if in doing so we may arrive at a fairer judgment of Dollond's work. That Chester Moor Hall was the real inventor of the achromatic telescope cannot be doubted to-day, but nevertheless J. Dollond's superiority over his optical brethren is evident, since when he introduced achromatic telescopes and opera glasses into the market he alone at that time realised the great progress brought about by Chester Moor Hall.

With regard to the questions raised by Prof. Pollard and Mr W. H. Towns as to the construction of drawn metal tubing, I should like to add to Mr Court's remarks that it is possible that Tulley (the father) as a comparatively young optician saw Martin's process, which was extensively used towards the end of the eighteenth century. Hence the interesting old draw bench mentioned by Mr W. H. Towns may stand in some relation to J. L. Martin's idea.

With regard to Prof. L. C. Martin's question concerning the origin of the two-lens astronomical eyepiece, Mr Court and I hope at some future time to be able to deal with a similar question in a short paper. We must ask for time, as our health is not very good and I personally have more work on my hands than I can easily manage. We shall of course offer a copy of our paper to Prof. L. C. Martin, who will perhaps kindly report on it.

Respecting the history of modern optical achievements, I hope to send, in a few weeks' time, a paper giving the history of the Jena works up to the time of E. Abbe's death. It is not improbable that some of it will be found interesting even in the respect mentioned by Mr F. Twyman, although I do not include manufacturing processes.

In concluding I must offer my best thanks to Dr Clay for reading our long paper and also for his kind judgment of my personal work. I am extremely glad of the deservedly high appreciation of Mr Court's part: without his wonderful knowledge and experience even his splendid Collection could not have given so decisive an impulse to the history of the optics of the old English telescope.

EXHIBIT OF THE MONOCULAR MICROMETER ("M.M.") UNIVERSAL THEODOLITE

By Messrs E. R. WATTS & SON, Ltd.

Exhibited 13th June, 1929.

The "M.M." Universal Theodolite has been designed to meet, as far as possible, the Specification drawn up by the Geographical Section of the War Office for an Ideal General Purpose Theodolite. A conference was held in May, 1927, at Tavistock and was attended by the principal officers of the Survey Departments of the Admiralty and War Office, and also by representatives of the various Surveying Instrument Manufacturers in Great Britain. Practical tests were carried out on Dartmoor with various pattern instruments including the new Zeiss and Wild theodolites, as a result of which a Specification was drawn up for an Ideal Theodolite.

The following are some of the characteristics of the new "M.M." Theodolite:

(1) The horizontal circle is three inches and the vertical circle two inches in diameter, consequently the instrument is extremely portable but it is of robust construction and not easy to get out of adjustment. The instrument and telescopic stand can easily be carried by one man even in steep and difficult country.

(2) The images of the opposite sides of both circles are viewed in one eyepiece conveniently placed at the side of the telescope, and are "meaned" by an optical micrometer. The observer can therefore, after pointing the telescope, without moving his position take readings from both sides of both circles, thus obviating the necessity of walking round the instrument at each observation.

(3) The graduations of both circles are read by means of the optical micrometer to single seconds with a minimum of fatigue and strain, and with an accuracy that could only be obtained otherwise by repeated readings on a much larger theodolite.

(4) The telescope is internal focussing, and will transit the eye end so that astronomical observations can be made with a diagonal eyepiece attachment.

(5) The theodolite is universal in its use, and is suited not only for triangulation of high precision, but also for all surveying where angle measurements are required, and for tacheometric work.

(6) The instrument is supplied with electric illumination for night or underground work.

(7) The manipulation of the instrument is so simple that observations can be made much more quickly than with the ordinary pattern of theodolite, with a consequent considerable saving in time and expense.

An illustration of the instrument is shown in Fig. 1 and the optical design is shown in Fig. 2. The graduations on both the horizontal and vertical circles are marked on the periphery of the glass circles, the surfaces of which are silvered over the graduations and figures. The images obtained of the graduations on the opposite

sides of the horizontal or vertical circle are brought together by the prisms *J*, *J*, and it therefore follows that the relationship of the two opposite sides of the circle to each other remains constant until they are finally viewed in one image by the eye-

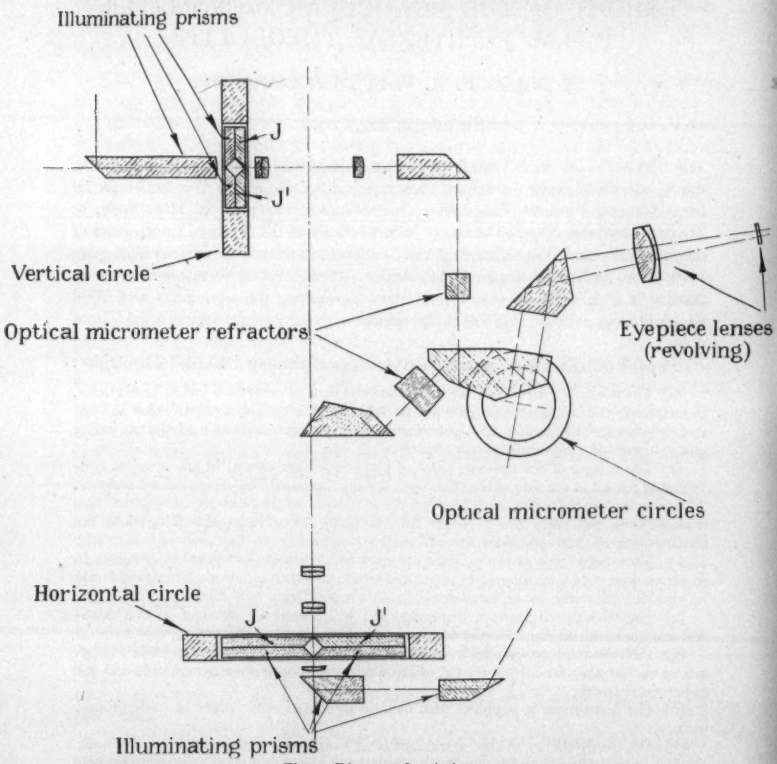

Fig. 2. Diagram of optical system

piece as shown in Fig. 3. This is a very important point, because, as a consequence, accuracy of reading does not depend on the absolute rigidity of the various optical elements.

The field of view of the monocular micrometer as seen in the eyepiece is shown

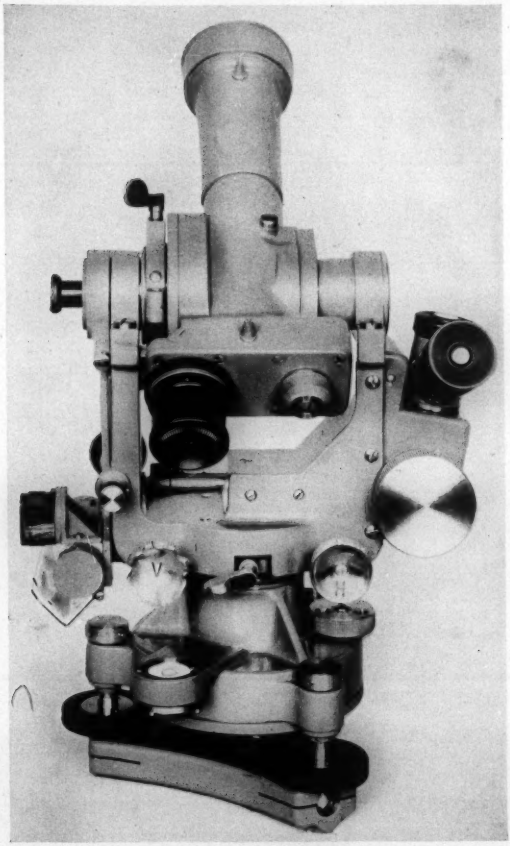

Fig. 1. The Monocular Micrometer ("M.M.") Universal Theodolite

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in Fig. 3. The images of the opposite sides of each circle are brought together on either side of a fine separating line, each in its respective field, and lettered "H" for horizontal circle, and "V" for vertical circle. The circles are divided into 20-minute divisions.

The exact residual reading is made by means of the optical micrometer. The micrometer milled head, when rotated, gives an apparent motion to the divisions which move in opposite directions and parallel to the separating line. When the

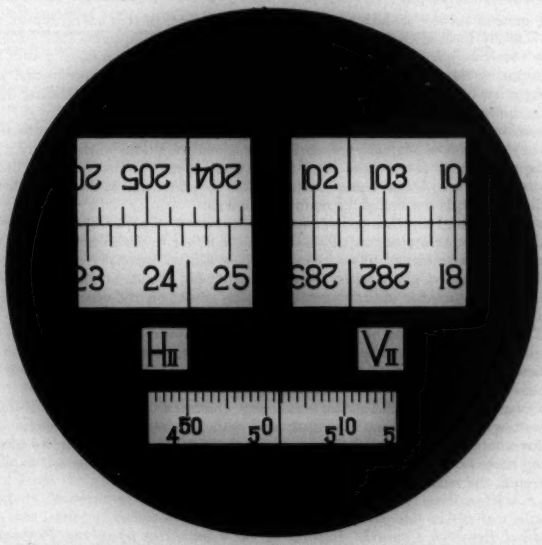

Fig. 3. Field of view of monocular micrometer

upper and lower graduations are exactly in coincidence, a reading is made, first by estimation to the nearest 10 minutes by means of the index line in the field, and secondly direct to minutes and seconds on the micrometer scale which is in the lower part of the field of view. A coincidence and reading must be made separately for each circle.

The method of reading for each circle in turn is:

(1) Coincidence.

(2) Reading of degrees and 10 minutes.

(3) Reading of micrometer to minutes and seconds.

REVIEWS

Medical Research Council. Reports of the Committee upon the Physiology of Vision. II. *Dark Adaptation* (*A Review of the Literature*). By DOROTHY ADAMS. Pp. 138; 26 Figs. (London: H.M. Stationery Office, 1929.) Price 5*s.* net.

The general subject of dark adaptation forms the basis of this useful report, but the matter actually noticed covers a much wider field, even dealing with such problems as Pulfrich's stereoscopic method of heterochromatic photometry. This is, no doubt, because observations on the state of adaptation are a *sine qua non* in most experimental work on visual capacity, but it has evidently given the author a difficult task in deciding what may safely be omitted.

The matters dealt with comprise the perception of achromatic and chromatic light stimuli in the course of adaptation to darkness, regional variations in the sensitivity of the dark-adapted retina, foveal and extra-foveal phenomena, factors causing individual variations, and so on. A final section deals with the theories (such as they are) which have been offered to explain some of the main phenomena.

The report brings together and summarises the results of papers published in a range of publications which are not usually all accessible either to physicists or physiologists; the references to continental physiological journals will be especially useful to members of the Optical Society. There will no longer be any valid excuse for the waste of time in repeating work which has already been adequately done; on the other hand, the report exhibits a good many tangled knots of conflicting evidence which call for further experiment. The necessary brevity of the summaries will, however, make it essential to refer to the original works, and it may even prove that a more searching examination of the contradictory results in regard to such matters as "the colourless interval" will lead to the discovery of new phenomena.

It is easy to appreciate the author's difficulty which led to the adoption of the terms "Empfindungszeit," and "Empfindungsdauer" without admitting that these are suitable words for adoption into English literature on the subject. Why must we always be importing these foreign words? The Germans are not afraid of adopting self-explanatory terms even at the risk of a little accuracy.

L. C. M.

Medical Research Council. Reports of the Committee upon the Physiology of Vision. IV. *Experiments on Binocular Vision.* By N. M. S. LANGLANDS. Pp. 69; 34 Figs. (London: H.M. Stationery Office, 1929.) Price 2*s.* 6*d.* net.

These very practical experiments on binocular vision undertaken by the author, Instructor Lieutenant-Commander N. M. S. Langlands, R.N., D.Sc., are published by the Medical Research Council, with the permission of the Admiralty. There will be general agreement with the prefatory statement of the Council that "Workers elsewhere will feel much indebted for this outcome of a system by which officers in the Royal Navy, if they have the right qualifications, are allowed so far as possible the necessary opportunities for producing original work of scientific value during the course of their ordinary duties."

The author may be congratulated on having available as observers an ample supply of experienced naval officers whose business it is to make accurate measurements, and on having access to the necessary laboratory equipment and workshop staff.

The contribution is divided into four parts: an introduction; an account of experiments

on binocular vision and vernier acuity; the measurement of binocular acuity for small illuminated discs in a dark field; and a discussion of the effect of variation of the duration of the illumination on the binocular acuity.

In any investigation of the phenomena of vision the experimenter must quickly realise how numerous and complex are the conditions that determine acuity of vision. The author has necessarily limited himself to certain aspects of binocular vision and has obtained results that are generally comparable with those of other workers, although direct definite comparison is not always easy.

Most of the experiments have a special naval character, the object observed upon being a silhouette of a ship having two masts with an intermediate funnel, the ship being viewed broadside on. The observer under test is asked to state whether or not an object of a particular shape placed some distance above the funnel by an independent operator lies before or behind the plane of the masts. This distance from the plane is progressively diminished. From the number of correct and incorrect results, and neglecting doubtful estimations, the author derives what he terms "the 50 per cent. zone."

It should be noted that the formula employed is based upon the approach of one object to the near neighbourhood of another, whereas in the actual experiments the object is brought into a plane determined by objects not in its near neighbourhood. Theoretically the formula is applicable to both cases: in practice, however, that may not be altogether the case.

Although the experimental results are of much interest, it is doubtful if the conditions really correspond with those of Naval Service, where instruments of a specialised character are employed. It is a necessary condition that the observer himself should bring the object into the plane of reference. He can then adopt the "above and below" method, whereby the greatest possible accuracy of observation is attainable. The object is set just appreciably in front, then just appreciably behind, and then the half-way between position is estimated. The difficulty of making comparisons between the results of various experimenters is very evident when the variety of methods of observation is considered.

Instantaneous illumination of the object was used in most of the experiments. At one time this question was regarded as very important, in view of the contention that stereoscopic vision, for example, depended upon movement of the eyes from one object to another. These questions have long since been settled. From the practical point of view, experiments of the instantaneous illumination type have less value. In Naval Service, for instance, the momentary illumination of a target by means of searchlights cannot be regarded from the physiological point of view as instantaneous. The laboratory results obtained are, however, of very particular interest, as they tend to confirm what is already known, that acuity of vision within wide limits does not depend on the intensity of the illumination.

Although the experiments are all of the binocular type, it would be interesting to know to what extent the results are binocular and not monocular, and it is to be hoped that the author will extend his experimental work into other fields and that, with the collaboration of the Admiralty and the Medical Research Council, these results again will be made available to other workers.

JAMES WEIR FRENCH

Medical Research Council. Reports of the Committee upon the Physiology of Vision. VI. *Some Experiments on Peripheral Vision.* By MYER SALAMAN. Pp. 47; 13 Figs. (London: H.M. Stationery Office, 1929.) Price 2*s.* 6*d.* net.

The report is divided into two parts describing experiments on the perception of movement and the perception of form in the peripheral regions of the retina. The object of the first series was to discover whether (in observing a moving object in the periphery

of the visual field) a perception of discontinuous change of position is ever obtained without that characteristic "movement" sensation which seems to be possibly connected with a very primitive type of visual activity, and secondly to discover whether discontinuous changes of position of a peripheral object are ever interpreted as "movement." In the second series, an investigation is made on the peripheral visual perception of lines and geometrical figures.

The experiments indicated that change of position of moving objects can be perceived at eccentric angles at which no characteristic movement sensation could be recognised. The angular movement of the objects was limited to a displacement subtending 6·9 degrees at the eye; then at speeds of the object of 0·2 degrees per second, and less, the change of position of the object can be recognised farther out into the periphery than the continuous movement. While, as Hartridge and Lythgoe have shown, the threshold for perception of movement at a given eccentric angle depends (other factors being constant) mainly on the angular speed, the perception of change of position depends not only on the displacement but on the speed also. While, perhaps, such results only confirm what might be generally anticipated the numerical results should be rather valuable. Full results are given graphically.

The illusory perception of movement obtained by discontinuous changes of position of a peripheral object was found to be very vague. The experiments were made with two point lights which could be exposed together or alternately, and their angular separation could be varied. As the result of many trials, the author reaches the conclusion that many observers have really obtained illusory perception of movement. He discusses the physiological basis of the illusion and throws a certain amount of doubt on the suspected close analogy between the visual perception of movement and Sherrington's "Immediate induction."

Description of such experiments is apt to lead the unwary into traps of phraseology; although the author has been very clear in most descriptions, the present writer had to look for some time at the passage concerning "the clearly perceptible disappearance of a peripherally observed object, the presence of which has ceased to be perceptible" until he realised that the disappearance of Peter may involve the appearance of Paul.

L. C. M.

The National Physical Laboratory—Collected Researches. Vol. XX, 1927. Pp. v + 444; 144 Figs. (London: H.M. Stationery Office, 1928.) Price 18*s*. 6*d*. net.

This volume of the Collected Researches of the National Physical Laboratory contains papers on optical subjects. Of the thirty here included twenty-one have been presented to the Optical Society and are reprinted from the Society's *Transactions*, four have been published in the *Proceedings of the Optical Convention*, 1926, two each in the *Proceedings of the Physical Society of London* and the *Journal of Scientific Instruments*, and one from the *Recueil des Travaux et Compte Rendu des Séances de la Commission Internationale de l'Éclairage*, 6th Session, Geneva, 1924.

In a sense, therefore, a detailed review of this valuable collection of papers on optical subjects is hardly necessary for readers of the Optical Society's *Transactions*. They have already had the opportunity of becoming acquainted with the individual papers; of discussing them at the Society's meetings and at the Optical Convention.

But it is not until one can see as a collected whole the output of the two departments of the Laboratory that deal with optics and optical instruments, that one appreciates fully the great contribution that is made to optical science and the optical industry by the Staffs of the National Physical Laboratory. A number of the papers, naturally, deal with the more fundamental aspects of the subject, and will possibly not appeal to men engaged in manufacture. A notable example is Mr T. Smith's paper on the Optical Cosine Law

which covers in one general form a number of the primary laws of optics. This is followed by half a dozen other papers by Mr Smith dealing with aberrations. Later in the volume are the important contributions by Mr J. Guild on Colorimetry and by Dr J. W. T. Walsh on Photometry.

The advantages of having all these important papers in one volume is very great.

T. Y. B.

Infra-Red Analysis of Molecular Structure. By F. I. G. RAWLINS, M.Sc., and A. M. TAYLOR, M.A. Pp. xv + 176; 35 Figs. (Cambridge: University Press, 1929.) Price 10*s*. 6*d*. net.

The book contains chapters on Gases, Liquids and Solids, a chapter on experimental methods and a mathematical appendix.

A feature which will make the book of much value to those pursuing investigations in this field is the collection of references given at the end of each chapter, a guide to which is formed by the text. On the other hand the book itself suffers in style by the tendency shown by the authors to write the "matter" round their references, a treatment which tends to emphasise the historical at the expense of the logical development of the subject, to the detriment of clearness. The book would probably be rendered more intelligible to the general student who did not possess a previous knowledge of the subject if its style were more didactic.

The chapter on experimental methods might have been expanded in length with great advantage, and made more critical in character. Statements that so and so used such and such a method are of little value to the student or investigator unless the many reasons which may have contributed to the choice of method are made clear by critical analysis.

The collected literature of this field of work which has appeared in English in book form is scanty, and one would have welcomed a fuller and more critical treatment. Nevertheless the book on the whole will be found to be a valuable guide to the recent developments of this increasingly important subject.

ABSTRACTS OF PATENT SPECIFICATIONS

286613. Holweck, F. REFLECTORS.

Oscillograph mirrors are formed by surfacing very thin films of celluloid. A glass ring is floated on mercury, and a solution of celluloid introduced. After evaporation and drying, the fine membrane is coated, preferably with magnesium, by thermal volatilisation of the metal upon it.

286684*. Soc. Technique d'Optique, etc. PROJECTION SYSTEMS.

An optical system for copying purposes consists of three lenses so arranged that the diaphragms of the outer lenses are in conjugate planes with respect to the central lens, which itself lies in a plane conjugate to the object plane with respect to the first lens, and to the image plane with respect to the last lens. The central lens may be replaced by a curved mirror, thus shortening the system by doubling back the optical axis.

286753. Everitt, W. REFRACTOMETERS.

A prism is secured to the movable portion of a ball race in such a way that the centre of one face coincides with the centre of rotation. A portion of the liquid to be examined is placed on the prism, which is then turned into the position of total reflection, as observed by an eyepiece, the necessary angular movement being read off on the scale.

286793. Turville, A. E. OPHTHALMOSCOPES.

The instrument, which may be used as an ophthalmoscope, retinoscope, or slit lamp includes a source of light and condenser lenses, between which stopping devices may be placed. Focussing lenses, which may be pivoted, are fitted within the tube of the instrument. Tilting mirrors and a battery of lenses may also be provided at the head of the instrument.

287088. Pintsch Akt.-Ges. VEHICLE LAMPS.

An optically corrected lens is placed in front of the bulb, which is fitted within a parabolic reflector having its axis tilted downwards. Behind the bulb, the reflector is spherical in shape. The front glass may be provided with distributing prisms.

287608. Barr and Stroud, Ltd., and another. OPTICAL APPARATUS.

Apparatus involving the use of optical means, such as deviation prisms, is employed for the purpose of the solution of data which can be represented in the form of a triangle. The solution depends upon the measurement of the displacement of an image from the centre of reference, determined in rectangular, oblique, or polar coordinates.

287643. Rtcheouloff, B. TELEVISION.

The picture is scanned by forming an image inside a photo-electric cell, in such a position that it can be traversed by a sensitive element mounted on the end of a spring. This spring is of such a character that it can be oscillated in two directions at right angles by electromagnetic means. A similar device is included in the receiver.

288269*. Zeiss, C. OPHTHALMIC APPARATUS.

The apparatus includes an illuminating system designed to avoid reflections at the cornea, and forming an image of the stop in the pupil of the eye; a camera for photographing the eye thus illuminated; and an observing telescope acting as a finder.

R. J. T.

* Specification published before acceptance.

PROCEEDINGS
AT THE
MEETINGS OF THE OPTICAL SOCIETY
1928–29

11th October, 1928

Meeting held at the Imperial College of Science.

Dr R. S. CLAY, President, in the Chair.

The following papers were read:

"Lenses and Equipment for Ultra-Violet Photography." By Col. J. WILLIAM GIFFORD, F.R.A.S.

"Some Remarks on Old English Objectives." By H. BOEGEHOLD, Ph.D.

"On the Development of Spectacles in London from the End of the Seventeenth Century." (First Paper on the Court Collection.) By THOMAS H. COURT and MORITZ VON ROHR.

Mr Z. A. MERFIELD of Melbourne University gave a short account of the history of the Grayson rulings, and exhibited specimens of various rulings.

8th November, 1928

Meeting held at the Imperial College of Science.

Dr R. S. CLAY, President, in the Chair.

Elections (Membership): Mr A. W. BALLANTYNE, Mr Z. A. MERFIELD, and Dr R. A. HOUSTOUN.
(Corporate Membership): THE EMIL BUSCH OPTICAL COMPANY.
(Student Membership): Mr G. E. COX.

The following papers were read:

"On Systems of Plane Reflecting Surfaces." By T. SMITH, M.A., F.Inst.P.

"Reflecting Surfaces for Image Inversion." By T. SMITH, M.A., F.Inst.P.

"The Relations between Field Illumination and the Optimum Visual Field for Observational Instruments." By Professor L. C. MARTIN, D.I.C., A.R.C.S., D.Sc., and T. C. RICHARDS, D.I.C., A.R.C.S., B.Sc.

13th December, 1928

Meeting held at the Imperial College of Science.

Dr R. S. CLAY, President, in the Chair.

Election (Membership): Professor A. M. TYNDALL.

The following papers were read:

"The Measurement of Axial Aberrations of Telescopic Systems of Small Magnification." By B. E. MOURASHKINSKY and Miss M. SAVOSTIANOFF.

"Notes on Skew Pencils traversing a Symmetrical Instrument." By T. SMITH, M.A., F.Inst.P.

8th, 9th, and 10th January, 1929

Nineteenth Annual Exhibition of Electrical, Optical and other Physical Apparatus, held at the Imperial College of Science, jointly with the Physical Society.

The following discourses were given:

"Experiments with High Frequency Sound Waves." By Professor F. LLOYD HOPWOOD, D.Sc., F.Inst.P.

"Lenses." By CONRAD BECK, C.B.E.

"Some Colour Problems in Photo-Engraving." By A. J. BULL, M.Sc., F.Inst.P.

17th January, 1929

Meeting held at the Imperial College of Science.

Dr R. S. CLAY, President, in the Chair.

Elections (Membership): Dr R. J. LYTHGOE and Mr J. G. BOWER.

Messrs C. J. BECK and R. W. CHESHIRE were elected to act as Hon. Auditors of the Society's accounts for the year 1928.

The following papers were read:

"The Functions of the Lens Capsule in the Accommodation of the Eye." By E. F. FINCHAM.

"A Double-reflexion Level." By D. S. PERFECT, M.A., D.Phil.

"Photographs of Reflexion Caustics." By T. SMITH, M.A., F.Inst.P., JOHN S. ANDERSON, M.A., D.Sc., F.Inst.P., and L. C. CORDLE.

14th February, 1929

Meeting held at the Imperial College of Science.

Dr R. S. CLAY, President, in the Chair.

Election (Membership): Mr F. C. MUSGRAVE.

The following paper was read:

"An Application of the Interferometer to the Goniometry of Prisms." By D. S. PERFECT, M.A., D.Phil.

Professor COKER's Photo-elastic Apparatus (1928 Model) was exhibited by Messrs Adam Hilger, Ltd., and described by their representative, Mr Hardy.

14th March, 1929

Annual General Meeting held at the Imperial College of Science.

Dr R. S. CLAY, President, in the Chair.

The Hon. Secretary presented the Annual Report* of the Council, which was approved.

The Hon. Treasurer presented his Report† and Balance Sheet‡, which were approved.

The Chairman read the list of persons nominated by the Council for office in the

* See p. ix. † See p. xii. ‡ See p. xiv.

year 1929–30 and declared all these duly elected as no other nominations had been received:

President: Mr F. TWYMAN.
Vice-Presidents: Mr D. BAXANDALL, Mr J. GUILD, Professor A. F. C. POLLARD, Mr F. C. WATTS.
Hon. Secretary (Business): Mr W. B. COUTTS.
Hon. Secretary (Papers): Mr A. WHITWELL.
Hon. Treasurer: Major E. O. HENRICI.
Hon. Librarian: Mr J. H. SUTCLIFFE.
Editor of Transactions: Dr JOHN S. ANDERSON.

Council:

Already serving:
Mr O. AVES.
Mr T. CHAUNDY.
Dr C. V. DRYSDALE.
Mr E. F. FINCHAM.
Mr E. T. HANSON.
Instr. Lieut.-Comdr. N. M. S. LANGLANDS.
Professor A. O. RANKINE.
Mr J. RHEINBERG.
Mr R. S. WHIPPLE.

Elected March, 1929:
Mr W. GAMBLE.
Mr J. W. HASSELKUS.
Mr R. KINGSLAKE.

Votes of thanks to the retiring Officers and Members of Council, to the Hon. Auditors, to the Governors of the Imperial College, with Prof. Callendar, for the use of the College premises for the meetings of the Society, and to Mr Banfield for his assistance at the meetings of the Society were unanimously passed.

14th March, 1929

Meeting held at the Imperial College of Science.

Dr R. S. CLAY, Past-President, in the Chair.

Elections (Membership): Mr D. ORSON WOOD and Mr A. W. HAWES.

The following papers were read:

"On the Testing of a Novel Photographic Shutter." By JOHN S. ANDERSON, M.A., D.Sc., F.Inst.P.

"A Re-determination of the Trichromatic Coefficients of the Spectral Colours." By W. D. WRIGHT, A.R.C.S., D.I.C., B.Sc.

9th May, 1929

Meeting held at the Imperial College of Science.

Dr R. S. CLAY, Past-President, in the Chair.

Elections (Membership): Mr J. ADAMSON.
(Fellowship): Mr G. A. RICHMOND, Lieut.-Col. W. BURDEN, R.A.

The following paper was read:

"Contributions to the History of the Worshipful Company of Spectaclemakers." (Second paper on the Court Collection.) By THOMAS H. COURT and MORITZ VON ROHR.

Mr COURT exhibited specimens from his collection illustrating the paper.

13th June, 1929

Meeting held at the Imperial College of Science.

Mr T. SMITH, Past-President, in the Chair.

Election (Membership): Mr H. P. HOLLIS.

The following paper was read:

"The Beam given by Dioptric Apparatus." By W. H. HAMPTON, Ph.D., B.Sc., F.Inst.P., A.I.C.

Experiments, Demonstrations, and Exhibits were arranged by Professor A. POLLARD and Professor L. C. MARTIN of the Technical Optics Department of the Imperial College of Science, through the courtesy of the Director, Professor A. O. Rankine.

New Theodolites were exhibited by Messrs E. & R. WATTS, Ltd., and Messrs COOKE, TROUGHTON & SIMMS, Ltd.

THE OPTICAL SOCIETY

REPORT OF THE COUNCIL TO THE ANNUAL MEETING OF MEMBERS, 14TH MARCH, 1929

THE COUNCIL of the Optical Society presents the following Report for the year ending 31st December, 1928:

During the year the Annual General Meeting, a Special General Meeting, and nine Ordinary Meetings of the Society were held at the Imperial College of Science and Technology by permission of the Governors and Professor Callendar, to whom the thanks and appreciation of the Society are due.

At the Special General Meeting in January an amendment to Rule 102 was adopted to conform with the arrangements made with the Institute of Physics mentioned in last year's Report.

On the recommendations made at a meeting of Representatives of the Institute of Physics, the Physical Society, and the Optical Society held in April, the Secretary of the Institute was appointed Assistant Secretary of the Optical Society, and the annual payment by the Society to the Institute was increased from £75 to £125.

At the Ordinary Meeting which immediately followed the Annual General Meeting in March, Dr R. S. Clay delivered the Presidential Address entitled "The Stereoscope" which was illustrated with exhibits of early instruments.

An important note entitled "Some Remarks on an Extension of the Optical Cosine Law" was presented by Dr M. Herzberger at the January meeting.

The Thomas Young Oration was delivered in May by Professor G. W. Ritchey. The Oration, which was entitled "The Modern Reflecting Telescope and the New Astronomical Photography," dealt with Professor Ritchey's achievements and his interesting and ingenious suggestions for the construction of giant telescopes. Several stellar photographs of unsurpassed merit were shown.

At the October meeting Mr T. H. Court and Professor Moritz von Rohr presented a comprehensive paper "On the Development of Spectacles in London from the end of the Seventeenth Century" which was illustrated with interesting exhibits from the extensive Court Collection.

The Society was indebted to Mrs Shurlock for the exhibition at the June meeting of a number of lantern slides illustrating "Studies in Diffraction" which had been prepared with descriptive notes by the late Mr F. W. Shurlock, and the Council have under consideration at the present time the possibility of publishing a selection from this comprehensive and unique collection of photographs.

At the February meeting Mr D. Baxandall gave a discourse on the Historical Collection of Optical Instruments in the Science Museum, after which, by the kind permission of Colonel Sir Henry Lyons, members were given facilities for a private view of the Collection, a special privilege which was much appreciated.

In conjunction with the Physical Society, the Eighteenth Annual Exhibition of Electrical, Optical and other Physical Apparatus was held at the Imperial College of Science and Technology on the 10th, 11th, and 12th January, and was attended by large numbers of people.

During the Exhibition, discourses were given by Mr A. Whitaker, of the Gramophone Company, on "Progress in the Recording and Reproduction of Sound," by Mr V. E. A. Pullin on "Recent Applications of X-rays," and by Dr J. W. T. Walsh on "Artificial Daylight."

Early in the year the Council appointed a sub-committee to consider the possibilities of arranging a discussion on photomicrographical apparatus, and it is hoped that this will take place during the next Session.

On the initiative of the President a preliminary discussion on the Standardisation of Optical Projection Apparatus was arranged by the British Engineering Standards Association between the officers of the Society, representatives of other learned societies, and of the manufacturers concerned. The discussion took place in June, the proposals put forward by the Optical Society were agreed to by the manufacturers, and it was arranged that a representative Committee should be formed to deal with the standardisation of certain component parts and accessories of optical projection apparatus. The President and Professor Pollard were nominated to serve on this Committee. The British Engineering Standards Association suggested that the Optical Society might consider the desirability of setting up further enquiries into the standardisation of other industrial optical products.

The Society took part as a Founder Member in the Seventh International Congress of Photography which was held at the Imperial College from the 9th to the 14th of July.

In September Professor Pollard and Mr Sutcliffe were appointed representatives of the Society to serve, with representatives of the Physical Society, on a Joint Library Committee formed by the Institute of Physics to assist in establishing a library and reading room for the use of the members of the Institute and of its participating Societies.

As in the past, members were invited by the Board of the Institute of Physics to attend the lectures on "Physics in Industry," and the Illuminating Engineering Society have issued invitations to all their meetings.

Mr R. S. Whipple has continued as the representative of the Society on the National Committee of Physics and Dr R. S. Clay has continued to represent the Society on the Board of the Institute of Physics.

LIBRARY

In addition to the regular Journals the following publications have been received during 1928:

Professional Papers of the Air Survey Committee:

No. 4. *The Stereoscopic Examination of Air Photographs.* By Lieut. M. HOTINE, R.E.

Penrose's Annual: The Process Year Book and Review of the Graphic Arts, vol. XXX. Edited by Wm. GAMBLE, F.R.P.S., F.O.S.

The Effect of Different Systems of Lighting on Output and Accuracy in Fine Work (Typesetting by Hand). Joint Report of the Industrial Fatigue Research Board and the Illumination Research Committee. By H. C. WESTON, M.J.Inst.E., and A. K. TAYLOR, A.C.G.I., M.I.E.E., A.M.I.C.E.

The Legibility of Print (Special Report Series No. 110 of the Medical Research Council). By R. L. PYKE, M.A.

Columbia University: Professional Courses in Optometry, 1928–1929.

Gesammelte Abhandlungen von Ernst Abbe. Band IV, erste Hälfte, Arbeiten zum Glaswerk zwischen 1882 *und* 1885.

The Theory of Light. By the late Prof. THOMAS PRESTON, M.A., D.Sc., F.R.S. Fifth edition edited by Prof. ALFRED W. PORTER, D.Sc., F.R.S.

An Atlas of Ophthalmoscopy. By Dr O. HAAB. Translated and edited by W. B. BARKER, F.B.O.A.

The National Physical Laboratory—Report for the Year 1927.

The National Physical Laboratory—Collected Researches, vol. XX.

Lehrbuch der Optik. By Prof. KARL FÖRSTERLING.

Ophthalmic Lenses. By H. H. EMSLEY, B.Sc., and WM. SWAINE, B.Sc., F.S.M.C.

Standards of Nomenclature and Measurement of Ophthalmic Products: recommended by the Ophthalmic Optical Standards Committee and adopted by the Institute of Ophthalmic Opticians and the Association of Wholesale and Manufacturing Opticians.

Amateur Telescope Making. Edited by ALBERT G. INGALLS.

Colour Photography. By Capt. OWEN WHEELER, F.R.P.S.

Bureau of Standards:

Journal of Research, vol. I, No. 2.

Research Paper No. 22. *The International Temperature Scale.* By GEORGE K. BURGESS.

Research Paper No. 31. *Effect of Temperature Change on the Colour of Red and Yellow Lovibond Glasses.* By DEANE B. JUDD.

Circular No. 13. *United States Government Master Specification for Lamps, Electric, Incandescent, Large, Tungsten Filament.*

Forschungen zur Geschichte der Optik, Band I, Heft I.

Transactions of the Optical Institute in Leningrad, vol. IV, Nos. 36–43.

The Russian Optical Society: List of Papers.

MEMBERSHIP

DURING the year fourteen Members, one Corporate Member, and one Student Member were elected. Seven Members resigned, four were removed, and three died. There is, therefore, an increase of two in the membership of the Society, leaving the number of Members on 1st January, 1929, as follows:

Ex-officio Fellow	1
Honorary Fellows	10
Fellows	113
Fellows non-resident in the British Isles	8
Members	120
Members non-resident in the British Isles	34
Corporate Members	9
Corporate Members non-resident in the British Isles	2
Student Members	9
Total	306

TREASURER'S REPORT FOR THE YEAR 1928

THERE is little that calls for special comment in the accounts for 1928. As stated in the last report, arrangements were made in 1927 for much of the clerical work, including the keeping of the accounts and the organising and clerical work of the annual exhibition, held in conjunction with the Physical Society, to be done by the staff of the Institute of Physics. This arrangement has worked well, but it was found, after a year's working, that the payment provisionally agreed on for these services was insufficient to cover the cost, and in consequence the rate of payment has been increased. This, together with the fact that the arrangement was only in force for a portion of 1927, accounts for the increase in payment to the Institute as compared with that shown in the 1927 accounts. The receipt shown as "Physical Society—Exhibition Account" is the Society's share of the excess of exhibition receipts over the out-of-pocket expenses directly chargeable to the exhibition, and should be considered as a contribution to the expenses incurred by the Society in organising the exhibition. The other expenses are normal.

The receipts for 1928 are all normal, but every item shows a small, but gratifying, increase over 1927. The net result is a balance of income over normal expenditure of £12. 11*s*. 11½*d*.

During the year, the accounts of the Optical Convention were closed, a further and final call of 20 per cent. being made on the guarantee fund. As the Society had guaranteed £200 and advanced the whole of this sum to the Convention, a refund of £10 has now been made to the Society, and the item "Optical Convention

Guarantee Fund" will not again appear in the balance sheet. The net result of this, and the balance of income over expenditure is that the Accumulated Funds account is reduced by £27. 8*s*. 0½*d*. to £501. 17*s*. 8½*d*. This completes the extraordinary expenditure sanctioned in 1925. The investments of the Society remain as in 1926 and 1927; their present market value is £664.

As usual, no credit has been taken in the balance sheet for the stock of the publications, books, or furniture, though these are insured against loss by fire for the sum of £300.

E. O. HENRICI,
Hon. Treasurer.

13*th February*, 1929.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDING 31ST DECEMBER, 1928

Dr EXPENDITURE

	£	s.	d.	£	s.	d.
To Printing and Stationery:						
Printing and distributing *Transactions*	450	2	8			
Office printing and stationery	37	8	9			
				487	11	5
Clerical assistance:						
Institute of Physics (includes administration of Exhibition)	112	10	0			
Editorial expenses	54	2	9			
Other expenses	19	8	0			
				186	0	9
Postage and receipt stamps				40	2	8½
Sundry expenses				38	13	3
Subscription to the Photographic Congress				5	0	0
Advertising				12	10	3
Balance, being excess of Income over Expenditure, transferred to Accumulated Fund				12	11	11½
				£782	10	4

Cr INCOME

	£	s.	d.	£	s.	d.
By Subscriptions:						
Fellows	249	8	0			
Members	162	15	0			
Corporate Members	31	10	0			
Students	3	13	6			
	447	6	6			
Less Rebate to members of the Institute of Physics	11	6	2			
Subscriptions written off	4	4	0	15	10	2
				431	16	4
Advertisements in *Transactions*, *less* expenses				29	8	6
Sale of publications				240	0	10
Interest				35	12	2
Physical Society—Exhibition Account				45	12	6
				£782	10	4

BALANCE SHEET AT 31ST DECEMBER, 1928

LIABILITIES

	£	s.	d.	£	s.	d.
To Sundry Creditors				272	10	10
Accumulated Funds:						
Balance at 31st Dec. 1927	529	5	9			
Less Call on Optical Convention Guarantee Fund	40	0	0			
	489	5	9			
Add Balance of Income and Expenditure account	12	11	11½			
				501	17	8½
Life Compositions account:						
Balance at 31st Dec. 1927	73	10	0			
Add Compositions made during year	21	0	0			
				94	10	0
Subscriptions received in advance				14	3	6
				£883	2	0½

ASSETS

	£	s.	d.	£	s.	d.
By Sundry Debtors				57	3	4
Subscriptions due				20	9	6
Optical Convention Guarantee Fund:						
As at 31st Dec. 1927	50	0	0			
Less final call	40	0	0			
,, cash refund	10	0	0	50	0	0
Investment:						
£650 5 per cent. War Loan (at cost)				657	6	3
Cash at Bank	130	4	6			
Cash in hand	17	18	5½			
				148	2	11½
				£883	2	0½

E. O. HENRICI,
Hon. Treasurer.

We have audited the above Balance Sheet and have obtained all the information and explanations we have required. We have verified the Bank Balance and the Investment. In our opinion such Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Society's affairs according to the best of our information and the explanations given to us and as shown by the books of the Society.

KNOX, CROPPER & Co.
Chartered Accountants

Spencer House,
South Place, E.C. 2.
22nd February, 1929.

Examined and approved on behalf of the Society.

7th March, 1929.

C. J. BECK,
R. W. CHESHIRE,
Hon. Auditors.

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